DESIGN OF AN ATTRACTIVE FRP BODY FOR A REFRIGERATOR

A Thesis Submitted
In Partial Fulfillment of the Requirements
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MASTER OF DESIGN

By

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to the

Design Programme

Indian Institute of Technology Kanpur

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CERTIFICATE

It is certified that the work contained in this thesis entitled **"Design of an Attractive FRP Body for a Refrigerator",** *by* **U V Sanandan**, *has been carried out under my supervision and this work has not been submitted elsewhere for a degree.*

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July, 2004

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to the “**designer**” himself

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I cannot forget the effort put in by Mr. Ram Siroman, who worked very hard, right from the fabrication of the patterns to the finishing of the refrigerator. It was great pleasure working with him. I also feel obliged to the members of ESA Lab, Mr. Anurag Goel and Mr. R.C. Tewari for helping me in various ways during the fabrication stage.

I would also like to express my heartfelt affection for all the friends of my design group as they made my stay at IIT Kanpur a memorable episode of my life. My friend, Ms. Prachi Jain needs a special mention here for being a constant source of inspiration to me right through this thesis.

Finally I would like to express my gratitude to my parents whose love and sacrifice has made me what I am today and my sister Pooja who has been a constant source of love and affection.

ABSTRACT

Right from the time the refrigerators, have been introduced; there have been very little innovations in the aesthetic and ergonomic front. Infact, all the concentration has been focused around improving the cooling technology, so as to keep the food fresh for a longer period of time.

The refrigerator body is made of mild steel (MS) sheet metal panels and the tooling cost involved in processing complicated shapes out of MS is quite high. Hence refrigerators are box shaped and intricate forms are not given. Even a slight intricacy increases the tooling cost exponentially.

In this thesis polymer composites have been used as an alternative material for making an attractive and efficient refrigerator body. A 100 liters prototype was developed after short-listing a concept from the many developed initially.

Various processes involved in the fabrication of the refrigerator out of polymer composites are pattern preparation, die making and the final component fabrication. Medium density fiber (MDF) and Polyurethane foam (150 kg/m^3) (PUF) were used to make the pattern. The die and the final component were made of polyester resin and glass fiber. Wet lay up technique was used for casting the die and the component. PUF ($35kg/m^{3)}$ was used as the insulation layer and structural member for reinforcing the cabinet. The refrigerator cabinet and the door were finally assembled and painted to give it a finished look.

Some of the salient features of the product are that, the body is made up of only two parts, consisting of the door and the cabinet, it is light in weight, tooling cost is reduced, and most importantly better a form is achieved.

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Chapter1

INTRODUCTION

1.1 BACKGROUND

Refrigerator, A quintessential device is found in more homes than any other appliance. It is one of those miracles of modern living that has totally changed life. The primary function of a refrigerator is to provide storage space for perishable/non-perishable food items at a reduced temperature. Prior to refrigeration, the only way to preserve food was to salt it and iced beverages in the summer were a real luxury. Cold temperatures help food stay fresh longer. The basic idea behind refrigeration is to slow down the activity of bacteria (which all food contains) so that it takes longer for the bacteria to spoil the food.

The refrigerator usually has a normal cooling area and a freezer compartment. A temperature of 0 – 10°C is maintained in the normal cooling area whereas a temperature in between –6°C and -18°C is maintained in the freezer compartment. The refrigerator is usually insulated with polyurethane foam (PUF) sandwiched in between the sheet metal outer housing and vacuum formed polystyrene inner housing. Depending on the need, different configurations of refrigerators are available in the market.

But traditionally the shape of a refrigerator has remained box shaped; mainly due to material constraint of mild steel. This thesis delves into development of different forms for the refrigerator by exploiting the material properties of composites.

1.2 HISTORY OF REFRIGERATION

Before mechanical refrigeration systems were introduced, people cooled their food with ice and snow, either found locally or brought down from the mountains (Fig 1.1). Meat and fish were preserved in warm weather by salting or smoking.

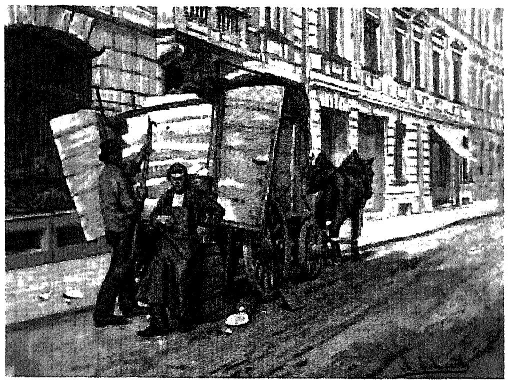


Fig. 1.1: Ice being carried from mountains

The Chinese are known to have stored ice obtained from natural sources, from as back as 1000 B.C. Around 500 B.C. the Egyptians and Indians made ice on cold nights by setting water out in earthenware pots and keeping the pots wet. In 18th century England, servants collected ice in the winter and put it into icehouses, where the sheets of ice were packed in salt, wrapped in strips of flannel and stored underground to keep them frozen until summer.

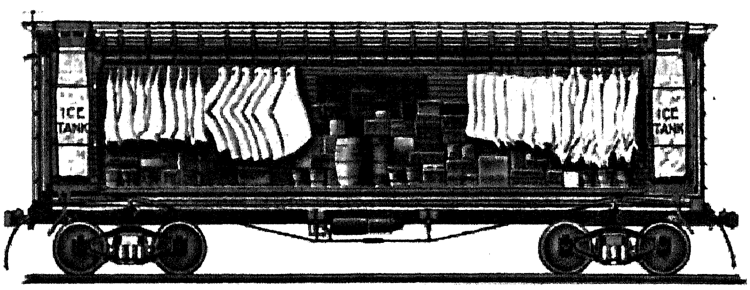


Fig. 1.2: Ice Train for transporting perishable goods.

At the beginning of the 19th century, iceboxes were used in England. Natural ice was harvested, distributed and used in both commercial and home applications in the mid-1800s. The ice trade between Boston and the South was one of the first casualties of the Civil War. Wooden boxes (Fig 1.3) lined with tin or zinc and insulated with various materials including cork, sawdust, and seaweed were used to hold blocks of ice and "refrigerate" food. A drip pan collected the melted water and had to be emptied daily.

Pioneers in refrigeration included Dr. William Cullen, a Scotsman whose studies in the early 1700s dealt with the evaporation of liquids in a vacuum; Michael Faraday, a Londoner who in the early 1800s liquefied ammonia to cause cooling, and Dr. John Goorie of Apalachicola, Florida, who built a machine to make ice to cool the air for yellow fever patients in 1834. Today's compression refrigeration system operates on a concept adapted from Faraday's experiments.

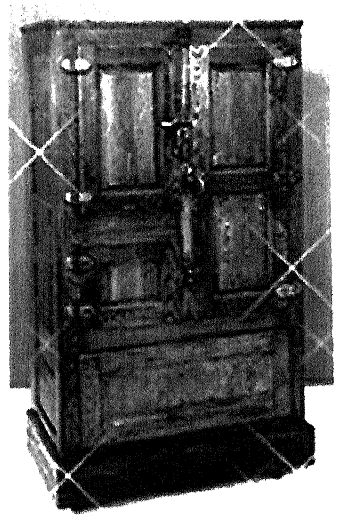


Fig. 1.3: Wooden Ice Box

Two of the first home refrigerators appeared in Fort Wayne, Indiana. In 1911, General Electric Company unveiled a unit invented by a French monk (Fig 1.4). In 1915 the first "Guardian" refrigerator, a predecessor of the Frigidaire, was assembled in Fort Wayne. In 1916 Kelvinator and Servel along with some two dozen other home refrigerators, were introduced to the U.S. markets. The number had increased to more than 200 by year 1920.

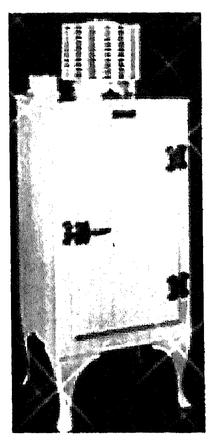


Fig. 1.4: GE's Monitor Top Refrigerator

In 1918 Kelvinator introduced the first refrigerator with an automatic control (Fig 1.5). In 1923 Frigidaire introduced the first self-contained unit (Fig 1.6). Steel and porcelain cabinets began appearing in the mid-20s. Mass production of modern refrigerators did not get started until after World War II. In the 1930s, Freon 12 was used to replace sulphur dioxide as the most commonly used refrigerant.

Fig. 1.5: A Kelvinator Refrigerator with automatic controls (1918)

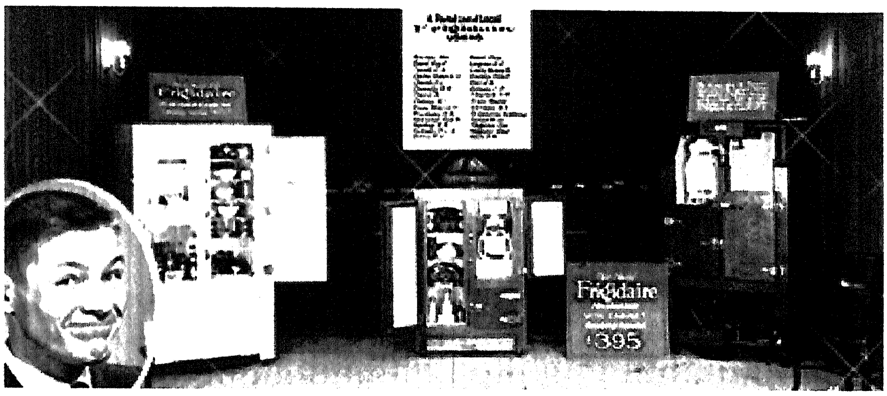


Fig. 1.6: Frigidaire Products (1920)

During the 1940s food preserved under frozen conditions became widely acceptable to consumers. Refrigeration technology began hopping in the 1950s and '60s when innovations like automatic defrost and automatic icemakers first appeared. The environment became a top priority in the 1970s and '80s, which lead to more energy-efficient refrigerators and elimination of chlorofluorocarbons in refrigeration sealed systems.

1.3 REFRIGERATORS: PRESENT SCENARIO

Across the market wide range of models varying in terms of capacity, cost, degree of automation and sophistication of use are available. With the advancement of technology, new ways of controls and interactions with refrigerators are possible. Some of the configurations of refrigerators/freezers available in the market are discussed.

Basically the refrigerator is a box shaped (Fig 1.6) structure with a door in the front. The initial designs of refrigerators had a top freezer single door configuration, with the freezer compartment placed inside the cooling compartment. The cooling compartment had several shelves to keep food items. The door had shelves to store bottles and other small items like eggs, butter etc. The capacity of these kind of refrigerators would vary from 90 liters to 200 liters. Subsequently the double door configuration was introduced. Where the freezer and cooling compartment had separate external doors. The capacity of these kind of refrigerators would range from 200 – 250 liters. However with the need for large capacity refrigerators coming up; configurations like side-by-side door and triple door, etc. have been introduced in the market. Capacity of these kind of refrigerators of the range of 300-800 liters. Side-by-side models have narrower double doors

In addition to these chest freezers are also available in the market. This configuration has a top door. Chest freezers are very efficient because they exploit the fact that cold air being heavy settles at the bottom. Hence whenever the chest freezer is opened there is not much loss of cold air and subsequently less power is consumed to maintain the temperature inside the freezer. However due to ergonomic problems they are not very popular in the households.

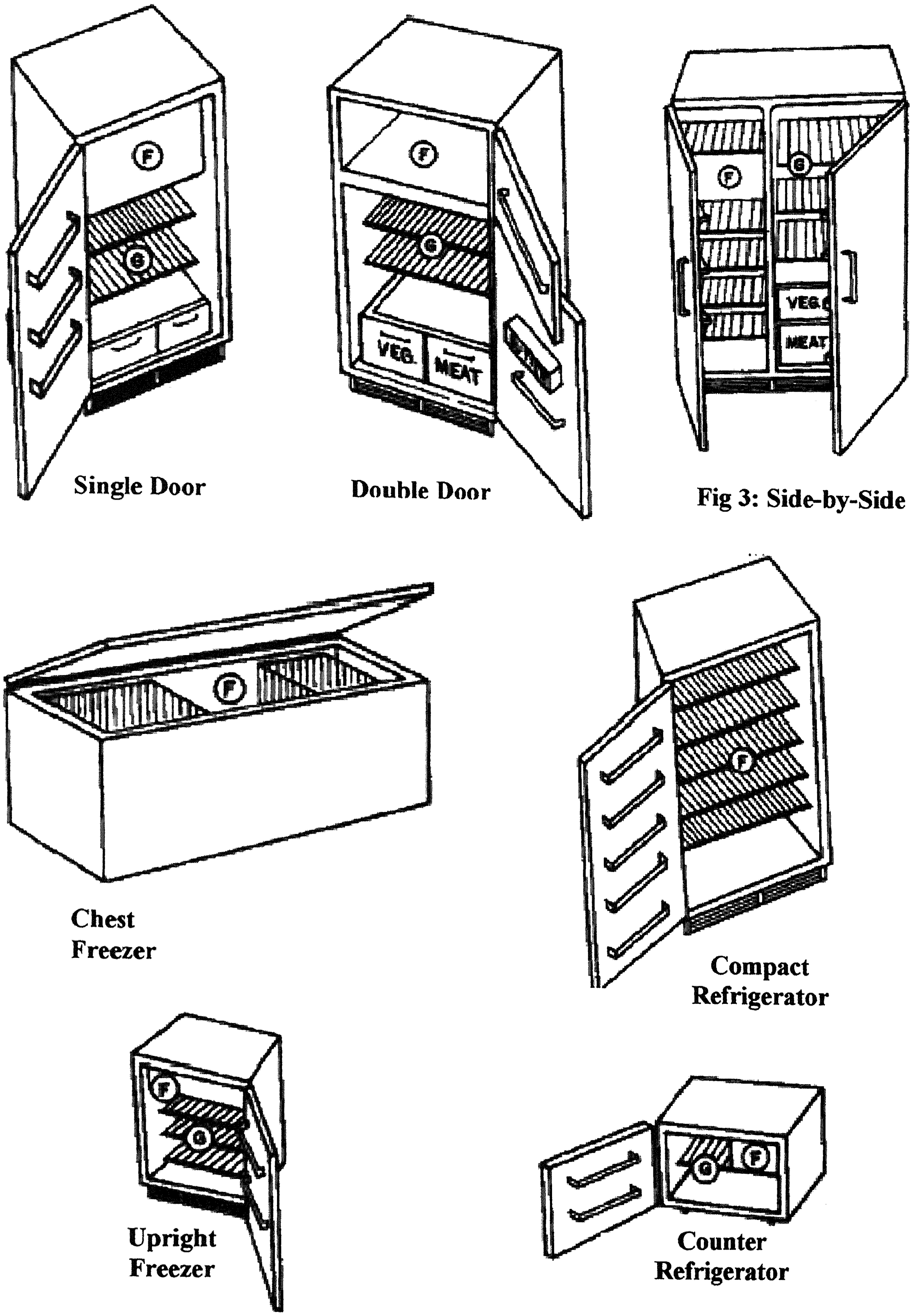


Fig 1.7: Various configurations of refrigerators

The present competitive market has seen new innovations of incremental nature in refrigeration technology. The market is booming with refrigerators flaunting technologies like Pentacool (Godrej) and Bio fresh (Samsung), related to circulation of air inside the refrigerator, and user friendly features like Frost-Free technology. Having an automatic defrosting systems means that users are not required to take everything out of the refrigerator to melt built-up ice in the freezer. An automatic defrost system includes a timer, a limit switch, and a heater that melts away frost.

One of the latest innovations in refrigerator industry is the intelligent refrigerator, For ex: LG is currently marketing refrigerators with intelligent features. These refrigerators are connected to the Internet and have an LCD screen. They can perform automatic maintenance and informs users about the problem via email. These features are expected to revolutionize the way users interact with the refrigerator

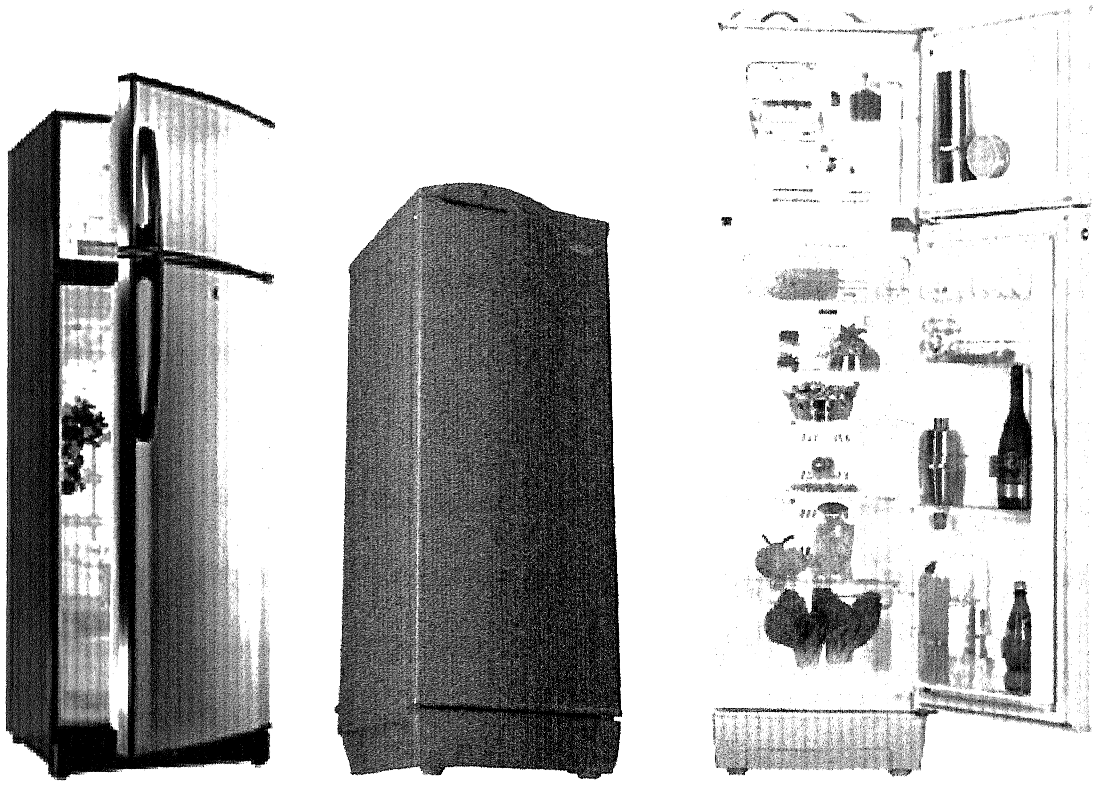


Fig1.8: Present day refrigerators

1.4 REFRIGERATOR FUNCTIONING

There are five basic parts to any refrigerator: **Compressor, Condenser, Expansion valve, Evaporator, Refrigerant.** Together these five parts form the cooling unit of the Refrigerator.

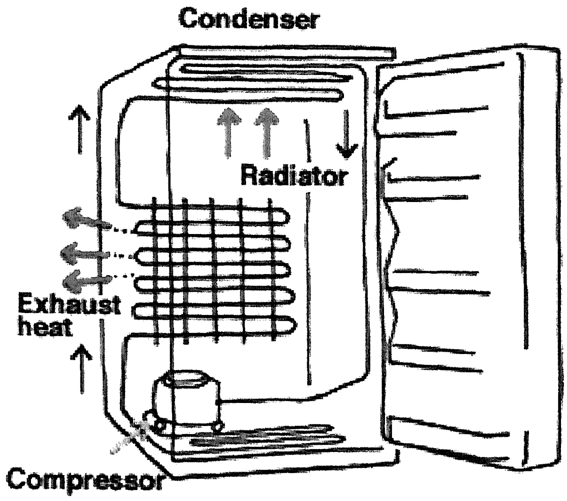


Fig. 1.9: Various components of a refrigerator

The basic mechanism of a refrigerator is as follows:

1. The compressor compresses the refrigerant gas. This raises the refrigerant's pressure and temperature (orange), so the heat-exchanging coils outside the refrigerator allow the refrigerant to dissipate the heat of pressurization.

2. As it cools, the refrigerant condenses into liquid form (purple) and flows through the expansion valve.

3. When it flows through the expansion valve, the liquid refrigerant is allowed to move from a high-pressure zone to a low-pressure zone, so it expands and evaporates (light blue). In evaporating, it absorbs heat, making it cold.

4. The coils inside the refrigerator allow the refrigerant to absorb heat, making the inside of the refrigerator cold. The cycle then repeats.

The refrigerator box is heavily insulated so that very little heat is absorbed from the outside air, and little cold air escapes. Most combination refrigerator-freezer units introduce chilled air into the freezer section; from there the cold air can pass into the refrigerator. Controls regulate how much cold air may pass into the refrigerator.

1.5 MANUFACTURING PROCESS OF A REFRIGERATOR BODY

The manufacturing of the body of the refrigerators consists of cabinet and door fabrication, pre-foam assembly, foam injection and final assembly. Foam injection is a critical process and needs very good control, both in terms of quality and quantity. As such the manufacturing process of a refrigerator body is similar across models.

A Refrigerator body is bade up of the inner housing and outer housing with Poly urethane foam in between. The inner housing is made of High Impact Polystyrene and is manufactured by the vacuum forming process. The outer housing is made of assembled MS panels. The assembly line of a refrigerator body consists of the cabinet fabrication area, pre-foam assembly area, foaming booth, post foam assembly area and the testing area.

The inner housing is mounted on to a frame. Electrical wires are laid up. The right and left side panel of the outer housing is then screwed to the frame. The evaporator tubes are laid up on the panels. The top portion, rear portion and the bottom portion of the refrigerator are then covered by a pre-fabricated card paper and sheet metal composite.

These areas are covered on the top and the rear by sheet metal and the bottom portion by compressor assembly.

In a typical refrigerator manufacturing company like Godrej, the foam injection process is carried out in an automated foam injection line. The injection line consists of several identical stations where refrigerator cabinets, the assembled inner and outer housing, enter after traveling by conveyor following the cabinet fabrication and pre-foam assembly areas. Once inside the station, each cabinet is held in place by a mold and is injected for 2+ seconds with chemicals that interact and expand to fill the space separating the inner and outer housing in a process that lasts up to 5 minutes. In the post foam assembly, the oil cooled compressor assembly is assembled onto the body. The electrical connections are made followed by brazing of the copper tubes to the compressor. The door shelves and other internal detailing are done followed by filling up of the compressor with the refrigerant. The refrigerator is then tested for leakage at various points and corrective action is taken.

The final assembly and manufacturing process of the refrigerator cabinet/door was studied at the Mumbai based Godrej Appliances Factory. Godrej Pentacool Double door model was studied. The process of refrigerator assembly is explained photographically in Fig 1.9 (a) and (b)

Inner housing of the freezer compartment.

Inner housing of the cooling area

Cabinet Assembly

Pre-Foam structure Passing through the oven

Foamed Structure

Foaming Booth

Compressor assembly

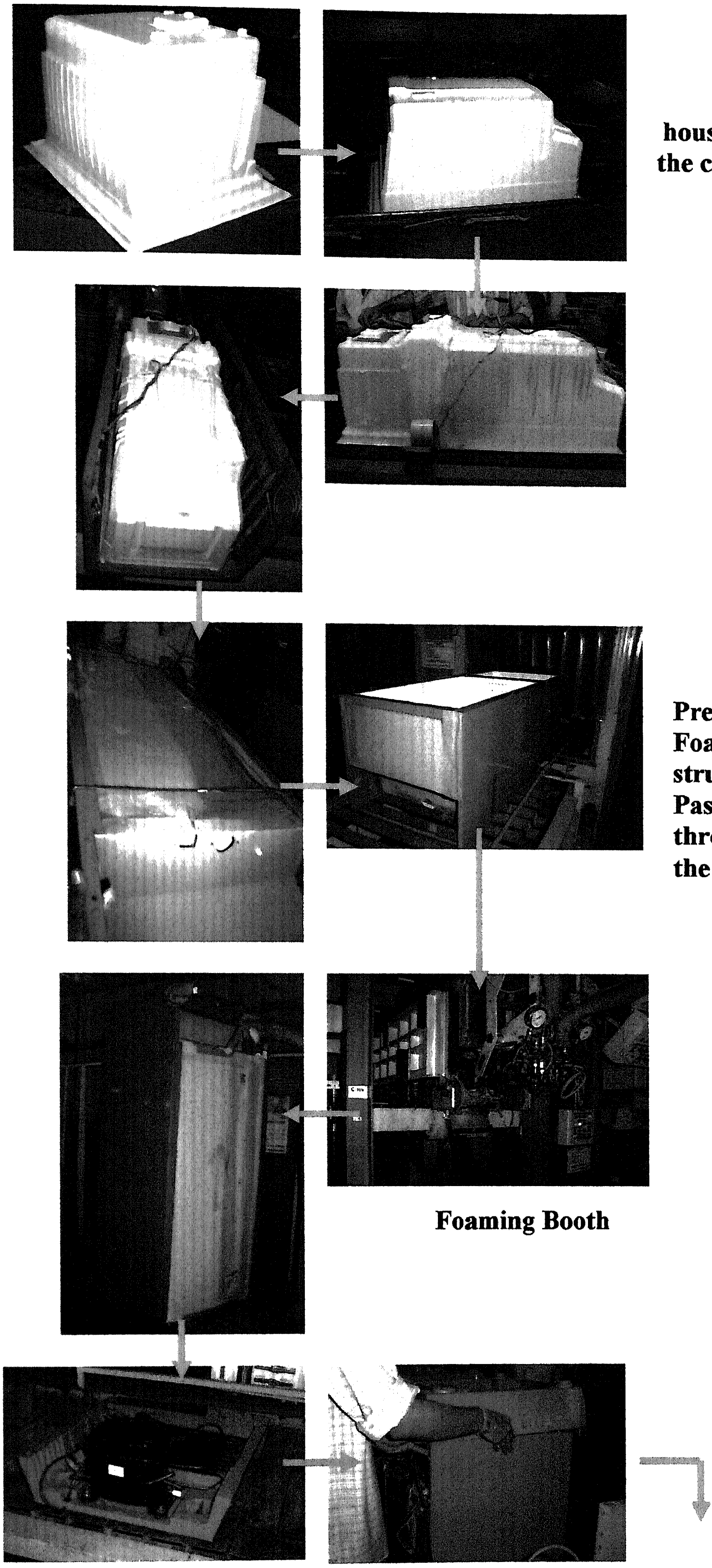
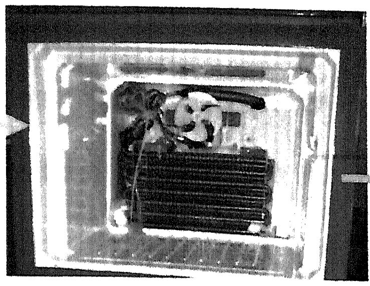
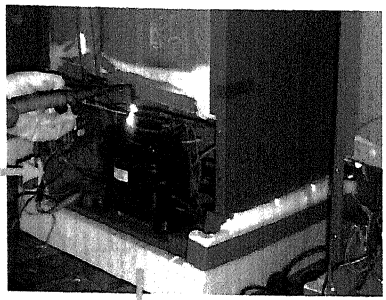


Fig. 1.9 (a): Refrigerator Manufacturing Process



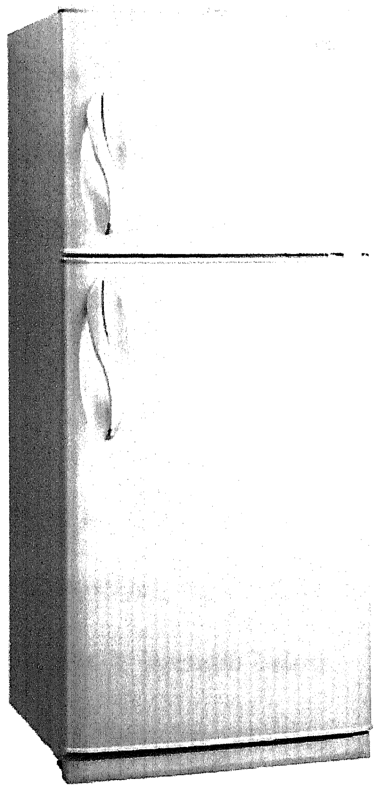


Cooling unit being connected to the compressor

Interiors are assembled and the doors are hinged

Finally the refrigerant is filled in the compressor and the fridge is tested for leakage and electrical problems and is subjected to routine quality control checks

Fig 1.9 (b): Refrigerator Manufacturing Process



Manufacturing a refrigerator involves assembling many components and it is a very labor-intensive work. It requires huge infrastructure even though it is not a technologically complex process. The refrigerator body is made of MS sheet metal but the tooling cost involved in processing MS for complicated shapes is quite high. Hence refrigerators have a box shape and intricate forms are not given. Even a slight intricacy increases the tooling cost exponentially. Hence any new model in the market differs only in the configuration and added technical features rather than in the form. MS also gets corroded over a period of time reducing the life of the product.

1.6 POLYMER COMPOSITES AS STRUCTURAL MEMBERS

Composite materials are made by combining two or more materials to give a unique combination of properties. Some widely used composites are GFRP, which consist of fibers and a polymeric matrix material; these composites can be thermoplastic or thermosetting in nature.

They have been routinely designed and manufactured for applications in which high performance and lightweight are needed. New material innovations and a drop in pricing and development of improved manufacturing processes have given rise to the presence of composite materials in almost every industry sector. In fact, because of

excellent styling capabilities with high quality surface finish quality attainable, composites are considered material of choice for certain industry sectors for ex: automobiles. The aerospace industry was the first to realize the benefits of composite materials. Broadly speaking the composite industry can be divided into the following industry categories: aerospace, marine, automotive, construction and civil structures, sporting goods industry, corrosion resistant equipment, consumer products etc.

The thermosetting type resin is a polymer that cures from a liquid to a solid through a chemical reaction of its two components. Once this reaction occurs, the material cannot be reprocessed. A typical thermosetting epoxy resin has a tensile strength below 70 MPa and is quite brittle. When such a resin is reinforced with glass fibers the resulting composite can have a tensile strength of 300 MPa. It also becomes extremely resistant to impact damage. This high strength for the relatively low weight is the fundamental reason that fiberglass composites are popular. Another significant reason is their tailor-ability. Since the reinforcement can be added in any direction, layers can be oriented to align more fibers in the direction of higher stresses. This saves additional weight by removing unnecessary material from areas with little stress. Other reasons for composite popularity are that they can be formed into complex shapes, that they have superior resistance to most environments and they can be used without a major investment in equipment.

They offer several advantages over traditional engineering materials like low tooling cost, capabilities for part integration, high corrosion resistance, good dimensional stability, high specific stiffness and strength, high fatigue strength etc. It has been observed that replacing steel components with composite components can save as high as

80 percent in component weight. The material offers greater flexibility for design changes in this competitive market where product lifetime is continuously reducing.

1.7 PROBLEM DEFINITION

Inspiration, the ability to stimulate creative thinking has many sources. One of them is the stimulus inherent in materials. All along it has driven humans to make use of materials and make interesting forms. Composites are one of the great material developments of the 20th century. This thesis is an attempt to synthesize a composite. The aim of the project is to make an attractive and efficient refrigerator body from polymer composites, so as to achieve the following.

- Two piece refrigerator consisting of the body and the door
- Lightweight refrigerator door and cabinet. So that the housewife can move it like a furniture piece. In fact a small refrigerator can even be used as a trolley to be taken to the dining table
- To have better insulation
- To achieve good form and finish. Organic shapes are possible
- To reduce the tooling cost of a new refrigerator

Chapter 2

CONCEPT DEVELOPMENT FOR THE REFRIGERATOR BODY

2.1 BACKGROUND

Food preservation is one of the oldest technologies used by human beings. Refrigeration and freezing are probably the most popular forms of food preservation in use today. Snow and ice, cool streams, springs, caves and cellars were long ago used to refrigerate food. However, during the nineteenth century, numerous experimental devices were developed in an effort to achieve practical artificial refrigeration. Today refrigerator is the worlds most used appliance.

The present competitive market has seen new innovations of incremental nature in refrigeration technology; however, the "box shaped" look of the refrigerator still remains. This is mainly due to the material constraint. The tooling cost for MS increases exponentially as the intricacies increase. Composites have been routinely designed and manufactured for applications in which high performance and lightweight are needed.

They are also known for their part integration capabilities. And the objective of this thesis is to make an attractive and efficient refrigerator body from polymer composites.

2.2 CONCEPT DEVELOPMENT

The starting point of design is the identification of the need; and the end point is the full specification of a product that fills the need or embodies the idea. Between the design brief and the final product specification lie the conceptual stage, development stage and detailed design stage. Conceptual stage presents the way the product will meet the need, the working principle. Here the designer considers the widest possible range of ideas. However concept development requires a study of forms. This helps to understand what designs/ trends are popular among people. It also gives a platform for the designer to start his work and obtain innovative solutions. The refrigerator being a household product is used mostly by the housewives. Hence a photographic study of kitchen appliances was done for studying their styling details, color selection, proportions, ergonomics, etc. Blowers, suitcases and ATM machines enclosure are other products, which were studied for their organic forms applied to a traditionally box shaped structure.

In this thesis, concepts have been developed for;

1. Stylizing the complete body including the door. Concepts 2.1 to 2.6 have been generated for the complete body.
2. Stylizing the door only: Door being a prominent portion of the refrigerator, any change in the feature of the door definitely helps in breaking the monotony of a box shaped structure. Concepts 2.7 and 2.8 are generated for the door.

2.2.1 Concept 1

Figure 2.1 shows the details of the first concept for the refrigerator. The challenge was to break away from the traditional box shaped structure and come up with a feasible organic shape; this form was conceptualized while studying mini speaker systems (Fig 2.1a). The salient feature of the concept is the spherical bulge in the cabinet and the circular door.

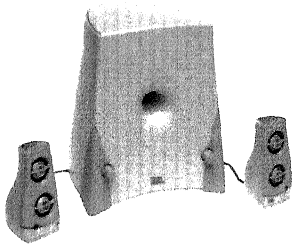


Fig 2.1a Mini speaker woofer system

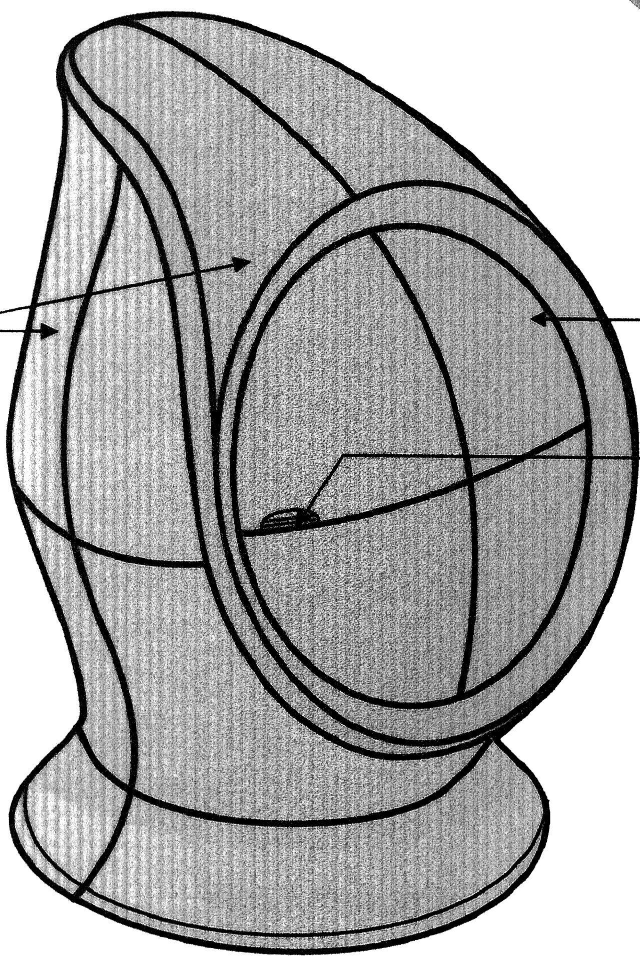


Fig 2.1: Concept 1

2.2.2 Concept 2

Figure 2.2 shows details of the second concept. This concept was derived from the first concept. The difference being the spherical bulge in the previous concept has been flattened and the cabinet has more of a cylindrical shape.

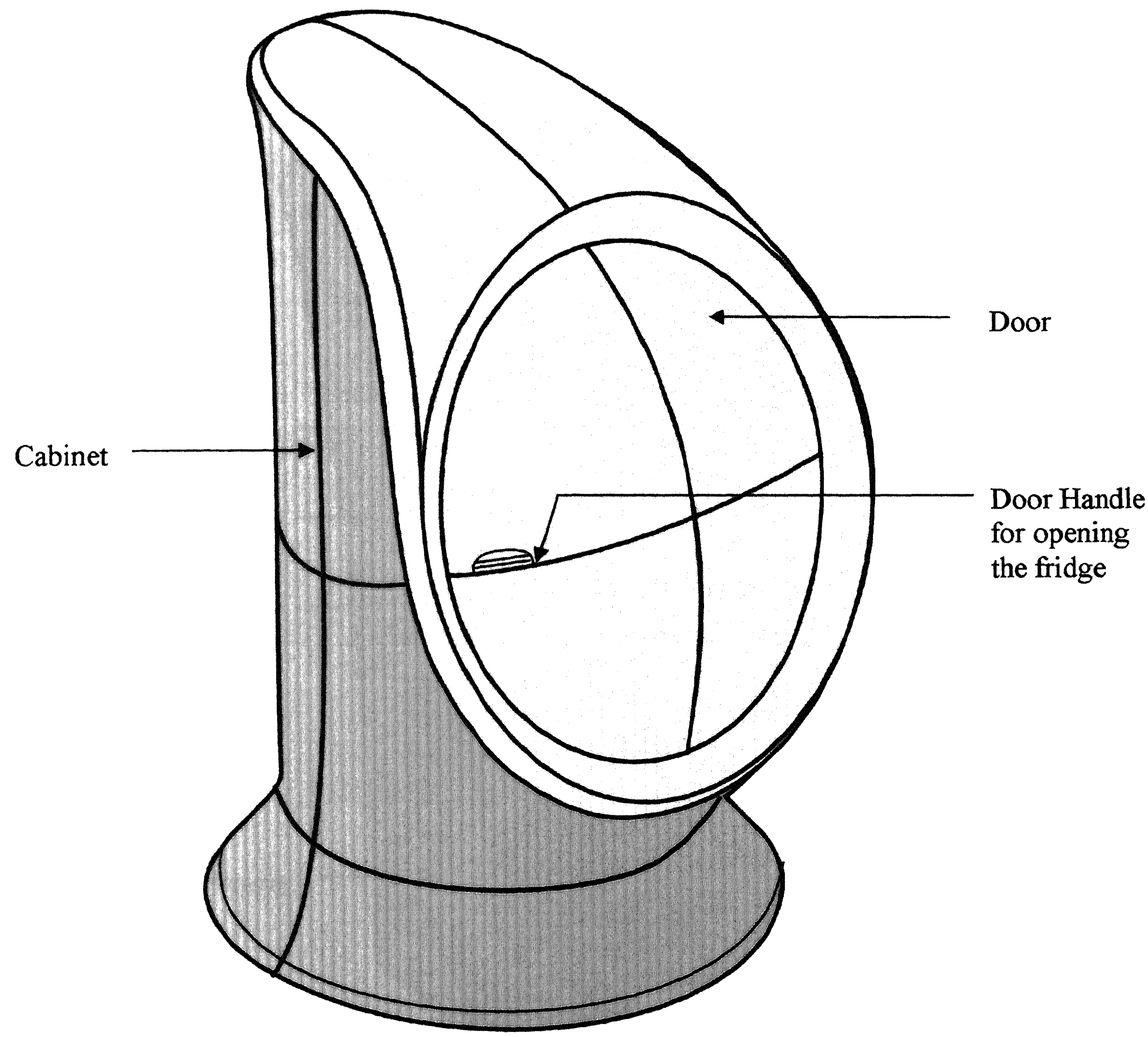


Fig 2.2: Concept 2

2.2.3 Concept 3

Figure 2.3 shows details of concept 3. This is a single door, bottom freezer concept. The bottom freezer does not have a door; instead it works on the sliding mechanism, Bottom-freezer models are gaining popularity because all areas of the refrigerator are more accessible. Capacity is about the same as standard models. Overall form of the fridge is pleasing. The shape of the door is the salient feature of the concept.

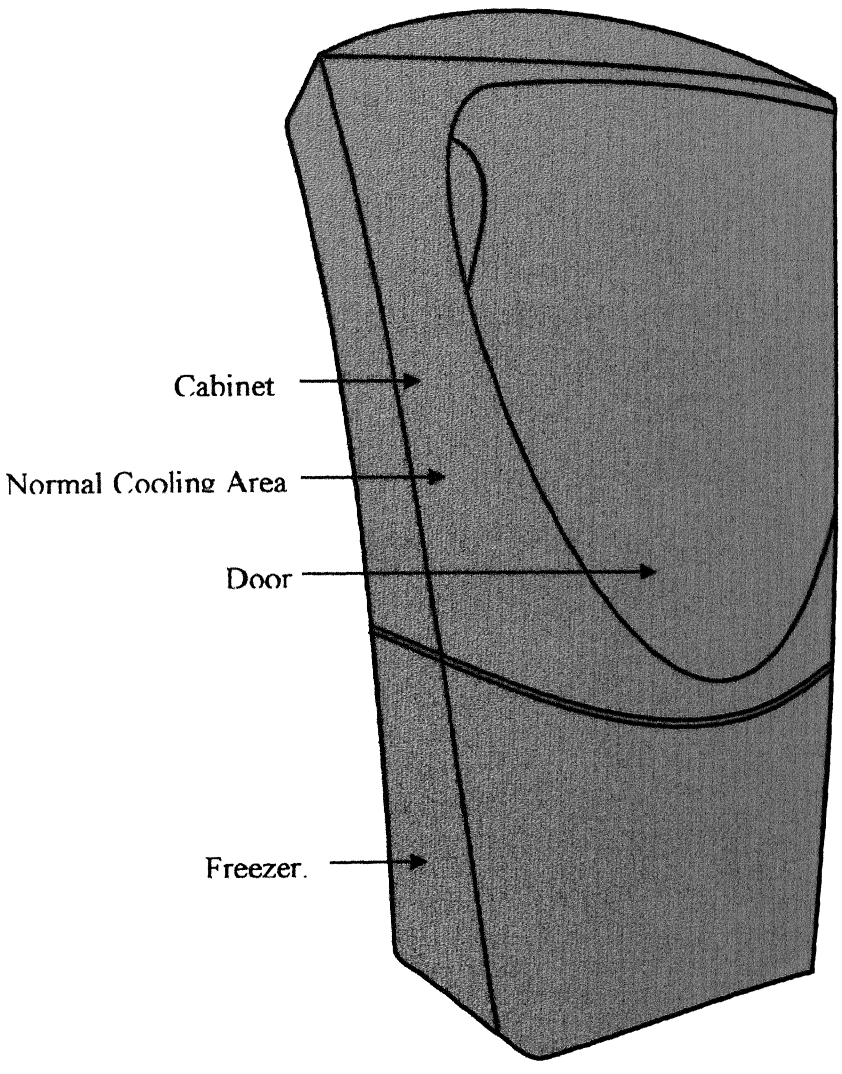


Fig 2.3: Concept 3

2.2.4 Concept 4.

Figure 2.4 shows details of the concept 4. This concept evolved while trying to generate forms out of clay. Aggressiveness is the theme of the form.

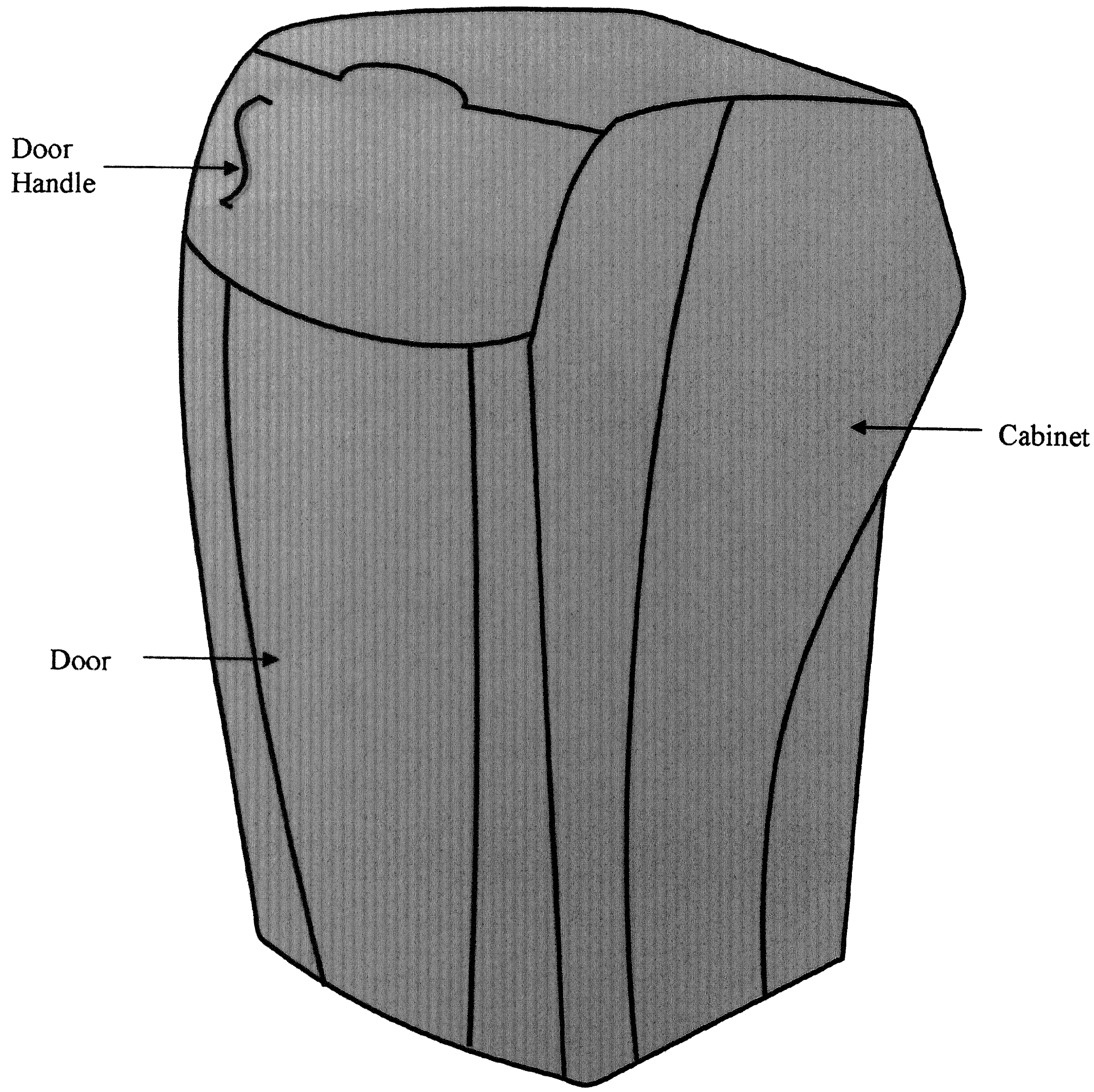


Fig 2.2: Concept 4

2.2.5 Concept 5

Figure 2.5 shows the details of concept 5. The form is inspired from that of an ATM machine. However the salient feature of the design is the door in door configuration. The idea being that it is not needed to open the main door every time we need to take a bottle of water or take any other small item out. Thus electricity consumption can be reduced and at the same time increasing the efficiency of the refrigerator.

Fig 2.5 (a) ATM Machine

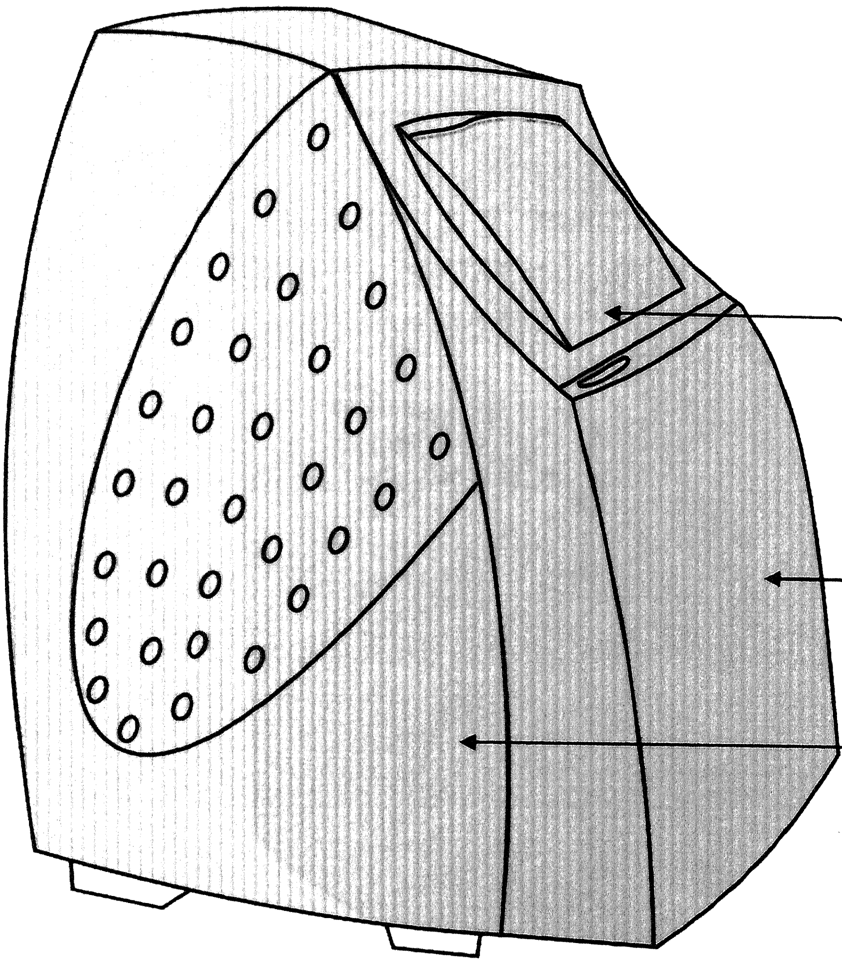


Fig 2.5: Concept 5

2.2.6 Concept 6

Figure 2.6 shows details of concept 6. To get maximum useful space inside the refrigerator, this form was conceptualized. The overall form remains box shaped but subtle design elements like curves and steps have been incorporated to break the monotonies of the box shape.

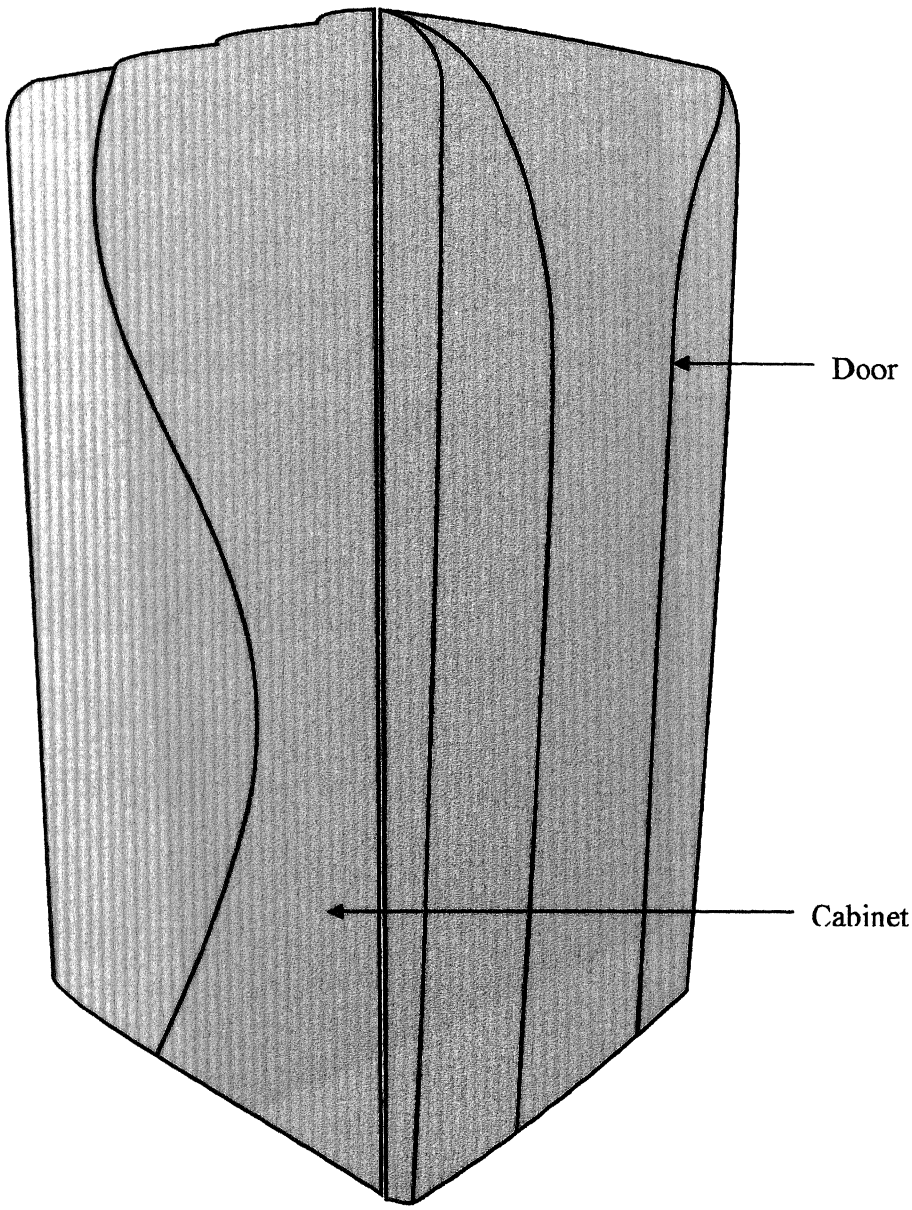


Fig 2.6: Concept 6

2.2.7 Concept 7

Figure 2.7 shows the concept for a refrigerator door. This concept was the first to evolve during the course of this thesis. Bold straight lines and sharp features are the characteristic of this concept.

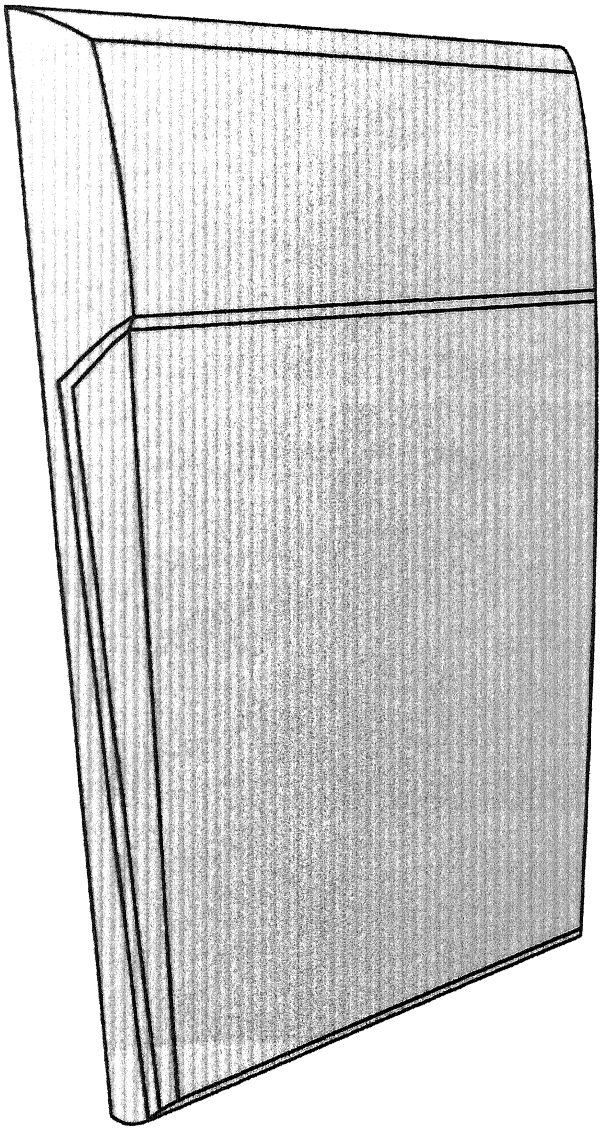


Fig 2.7: Concept 7

2.2.8 Concept 8

Figure shows the front view of the concept 8 for a refrigerator door. The human body was the inspiration behind this concept. Sharp features and gracious contours are the characteristics of this concept

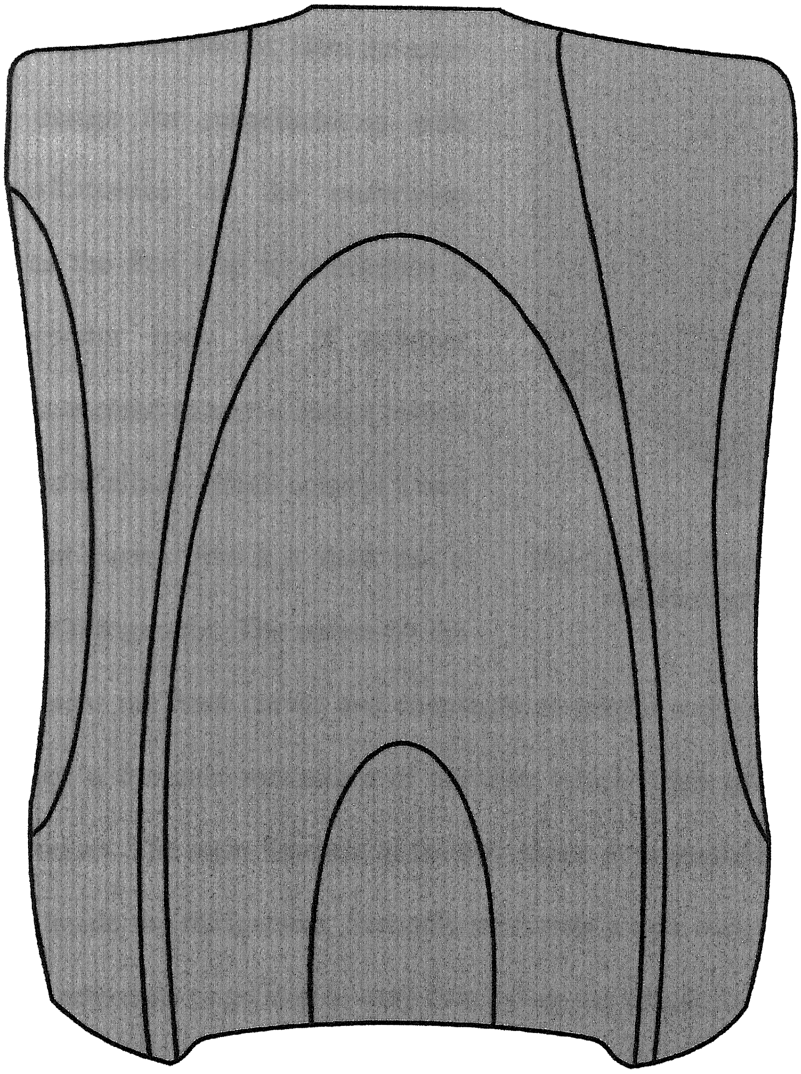


Fig 2.8: Concept 8

2.3 THE SELECTED CONCEPT

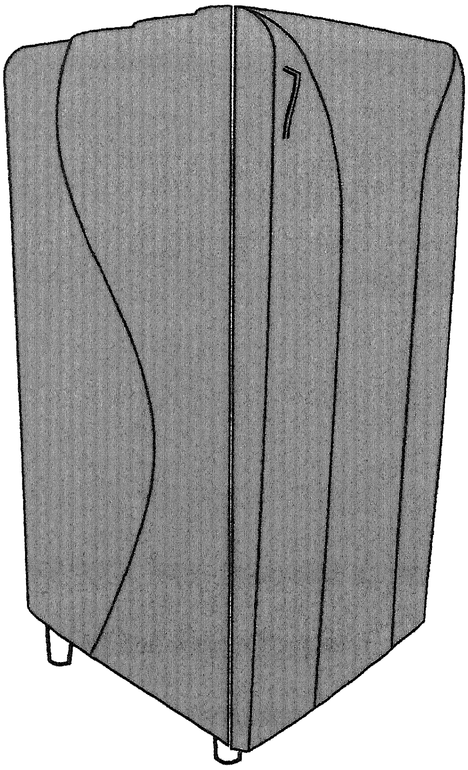


Fig 2.9: The Selected Concept for the Refrigerator Body

As discussed till now there are many possible concepts for designing a refrigerator body, however the choice of concept depends on the design's intention. Intentions describe the broad visions that guide the design. Here the main intention was design for manufacturing with design for performance as the underlying intention. And as the first step in developing a two-piece refrigerator body out of polymer composites it was decided to take a design, which could be easily materialized. Hence concept 8 was selected. The front curves give it a sleek and a stylish look to the refrigerator. The curves on the side face compliment the front curves and contribute to give it a rhythmic pattern. The curves bring about a dynamic movement of the eye, which helps gather the viewer's interest in the product. The main function of the box shape is to maximize the utilization of storage space inside the refrigerator. Secondly whenever a new material is being tried for a product, it is advisable to go step-by-step first trying out simple forms then venturing into complicated intricacies.

Chapter 3

PRODUCT DETAILING

3.1 BACKGROUND

In Chapter 2 various concepts for the refrigerator body were discussed. Concept No.8 was selected for its simplicity. Design for manufacturing and design for performance were the two criteria for short-listing the concepts. In this chapter the selected concept will be detailed.

The main scope of the problem is building a prototype of the refrigerator out of polymer composites. It will be non functional, that is, it will not have the cooling elements of a normal refrigerator like the evaporator coils, condenser coils, compressor etc. Accordingly the specifications are laid out.

3.2 SPECIFICATIONS

The main constraint of the product was to make a 1:1 scale prototype from polymer composites. The process to be employed was hand lay-up technique. Also one of the strong features of the refrigerator is that it was to be made of two pieces only, the

cabinet and the door. Hence, a small sized refrigerator of 100 liters capacity was finalized for fabrication. The refrigerator body would essentially consist of the Glass fiber reinforced polymer (GFRP) skin and an insulation layer. Polyurethane foam 35 kg/m^3 was used as the insulation layer. It was also used as a structural member for reinforcing the cabinet. The insulation layer was 25 mm thick. The overall dimensions of the refrigerator cabinet were 800 mm x 430 mm x 370 mm. and the dimensions of the door were 800 mm x 430 mm x 40 mm. Standard parts like the gasket for sealing the door, door hinges, door handle and the support legs for cabinet were procured from the market.

The curves on the door have been given to give the refrigerator a sleek and a stylish look. The curves on the side face compliment the front curves and contribute to give it a rhythmic pattern. The curves bring about a dynamic movement of the eye, which helps gather the viewer's interest in the product.

Figures 3.1 to 3.6 show the geometry of the door and body in various views. Figures 3.7 to 3.9 show the perspective views of the concept.

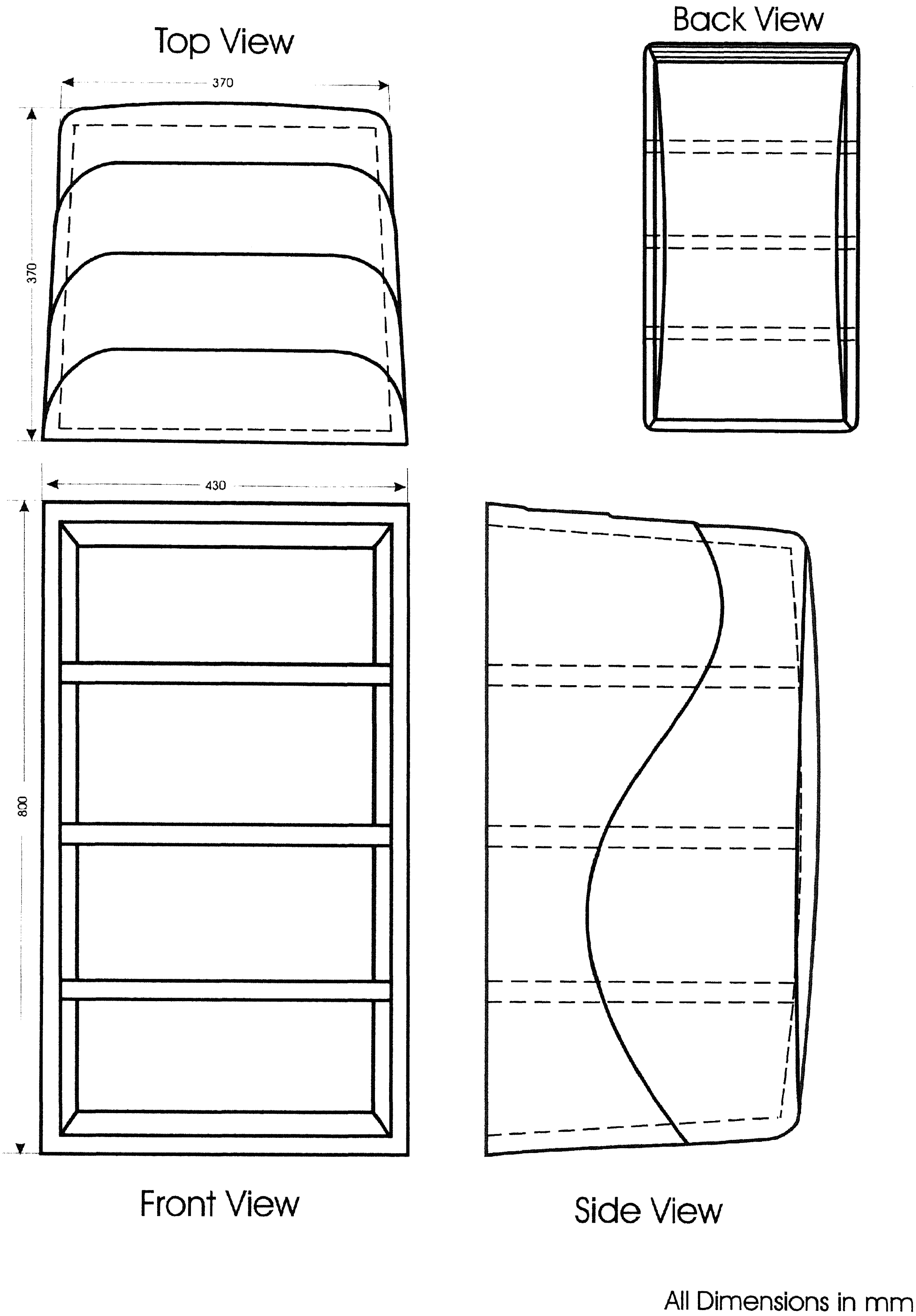
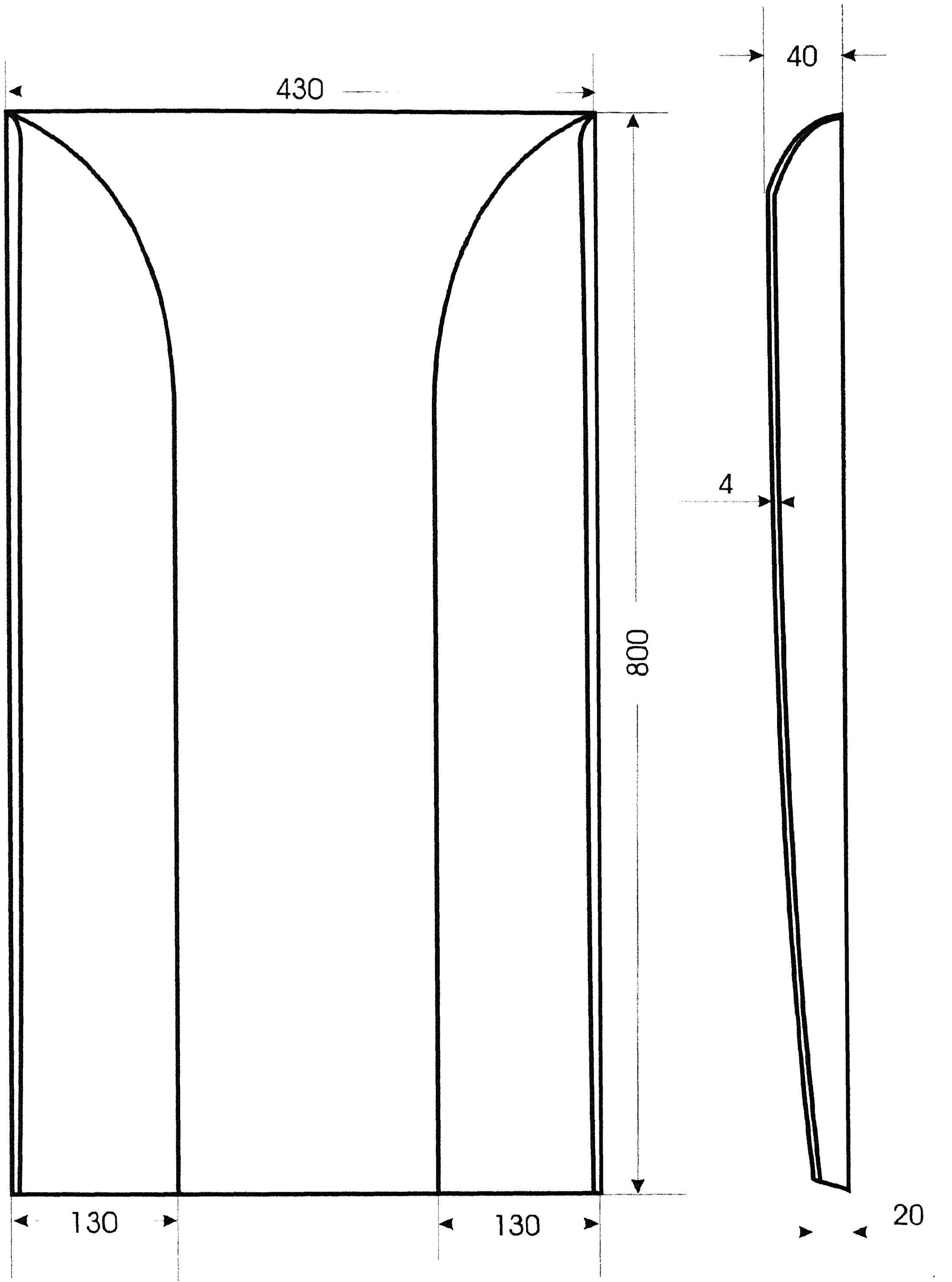


Fig 3.1: Fridge Cabinet



All Dimensions in mm

Fig 3.2: The Fridge Door

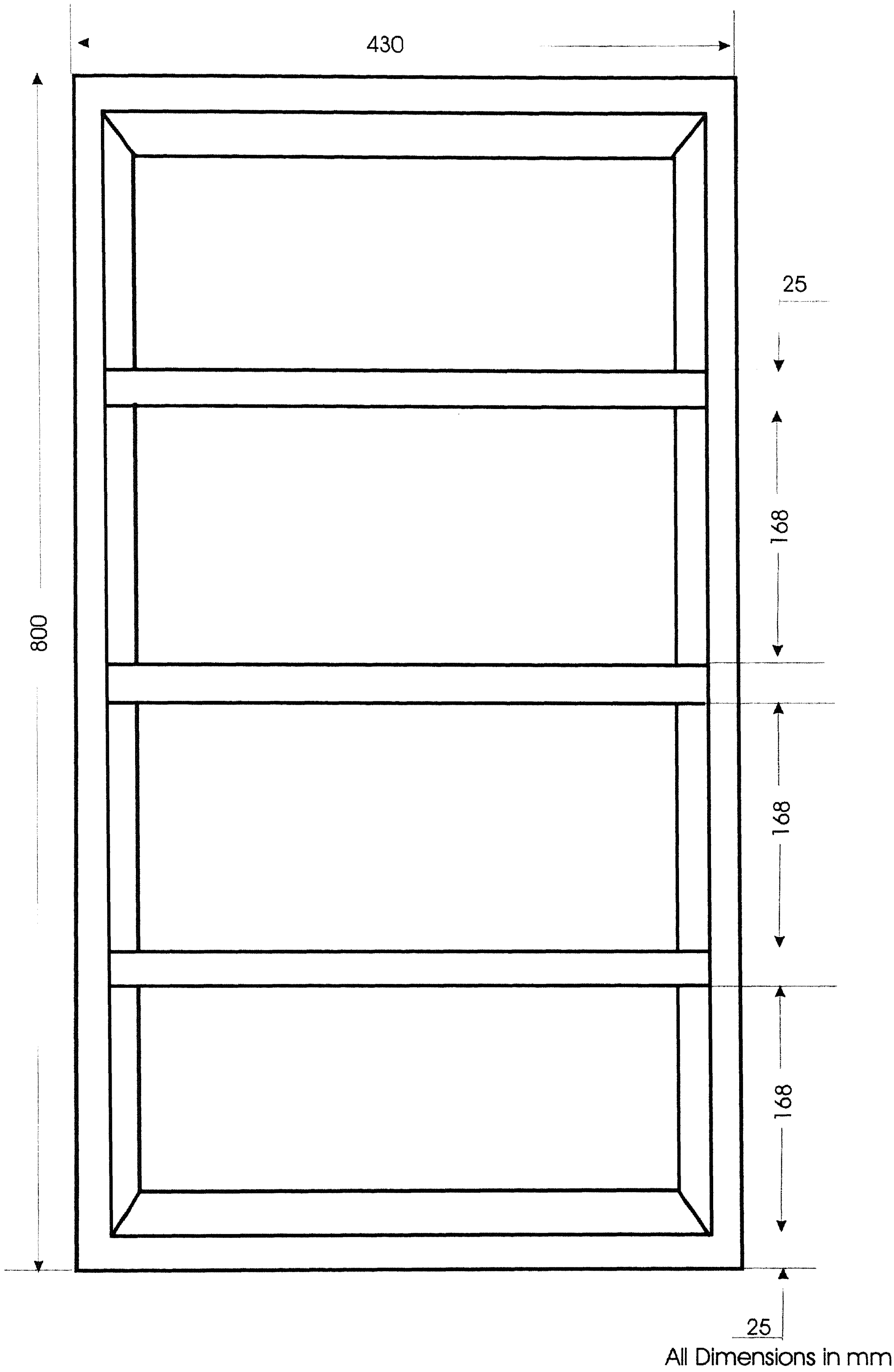


Fig 3.3: Details of the Front View of the Fridge Cabinet

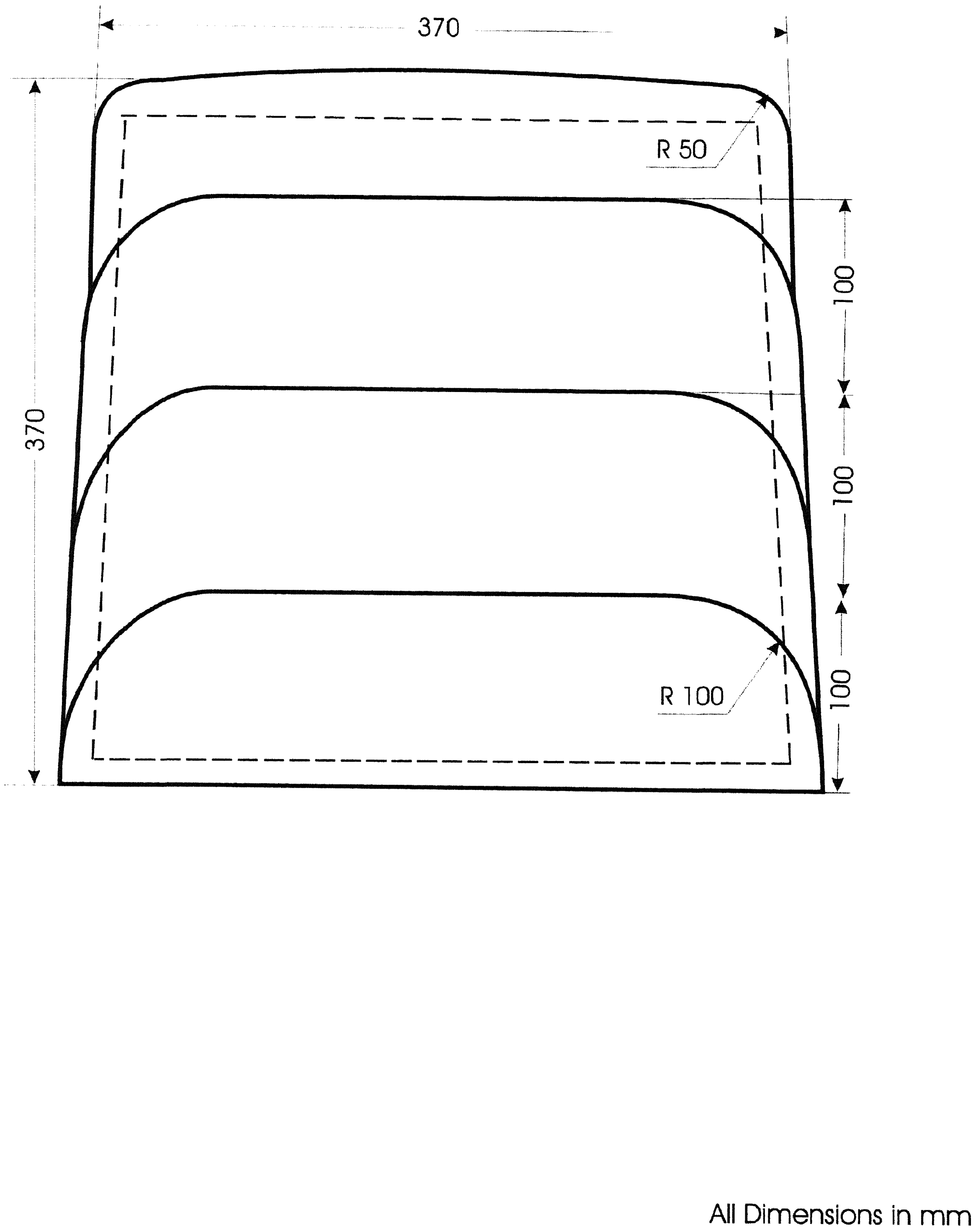


Fig 3.4: Details Of The Top View of the Fridge Cabinet

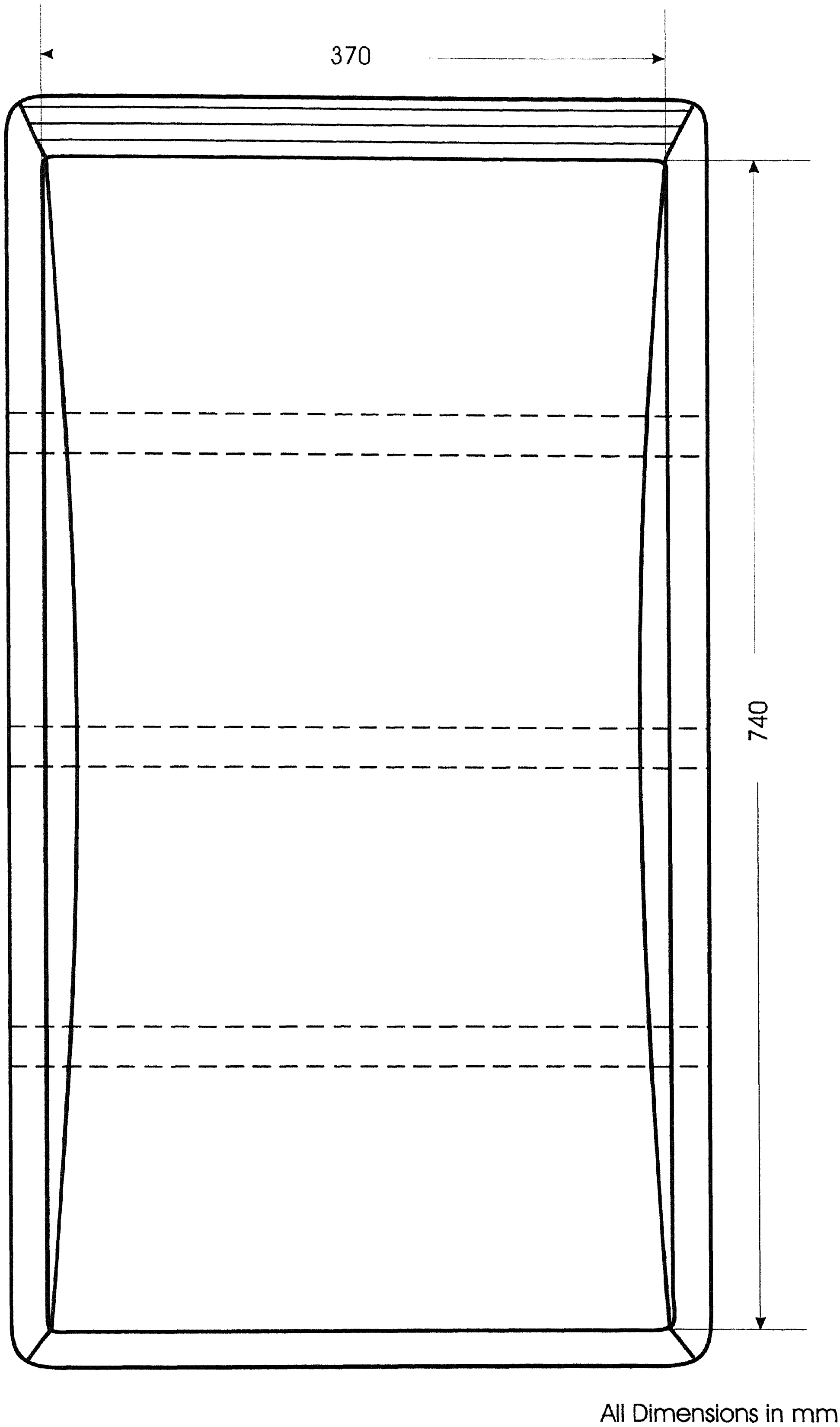


Fig 3.5: Details of The Back View of the Fridge Cabinet

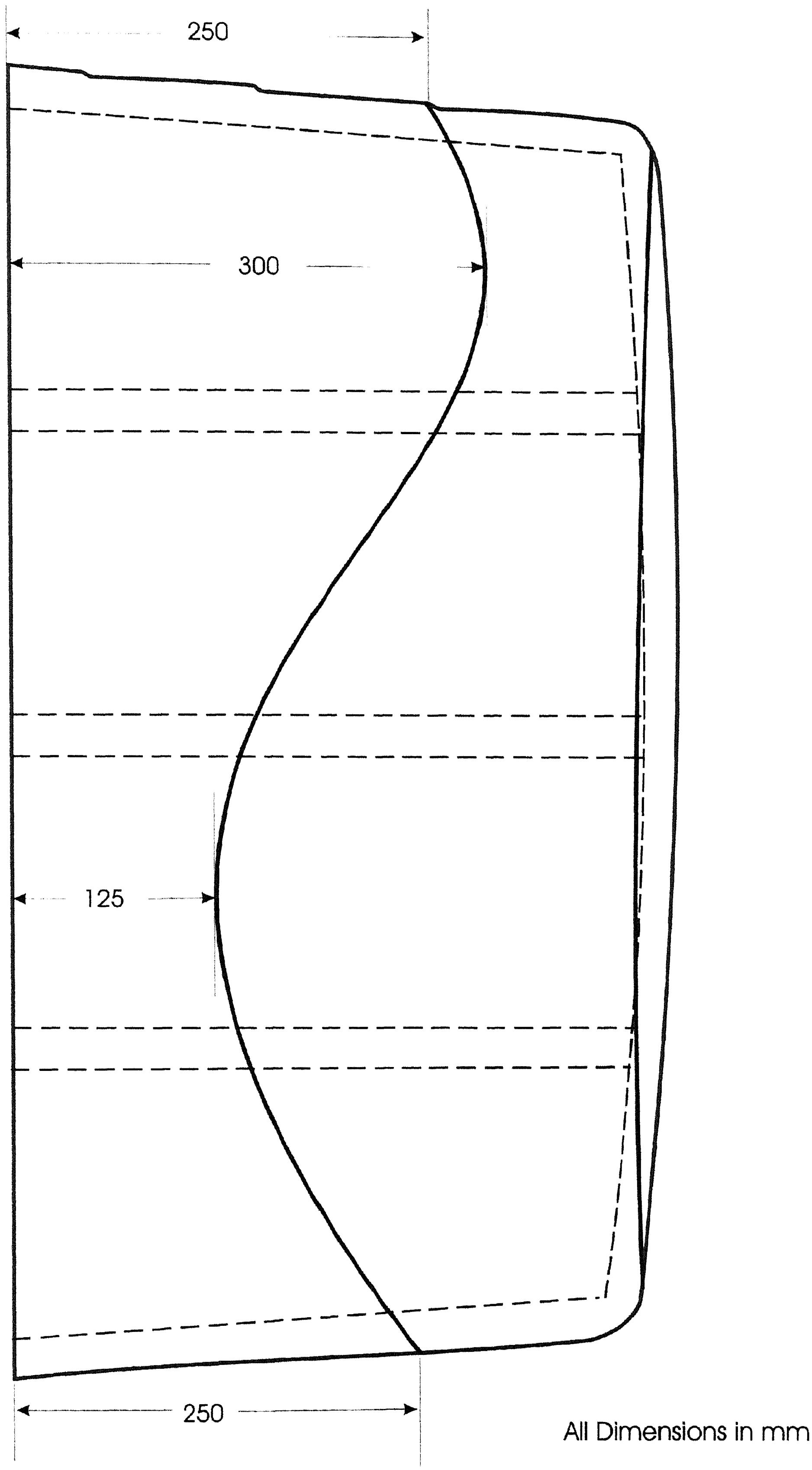


Fig 3.6: Details Of The Right Side View of the Fridge Cabinet

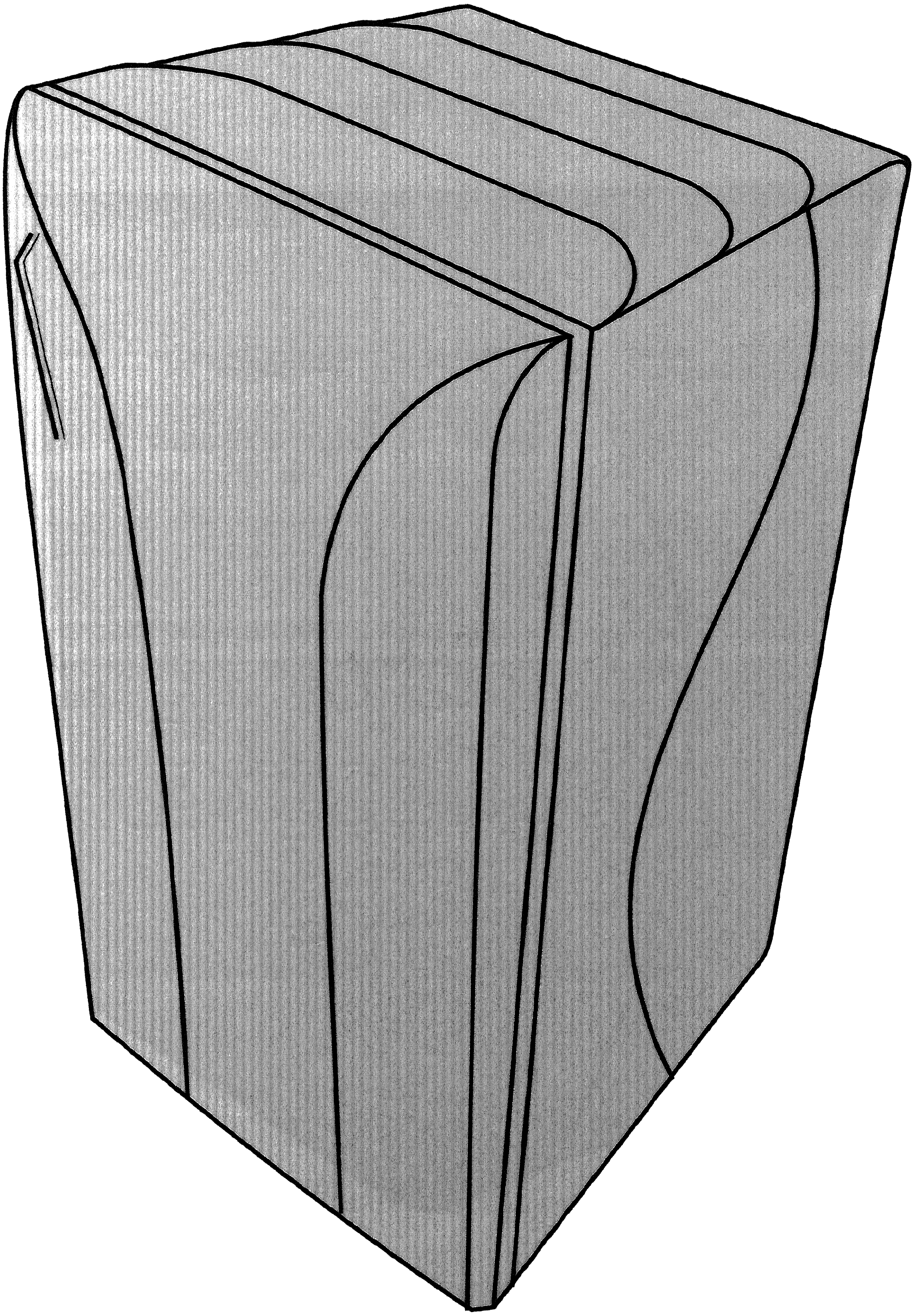


Fig 3.7: Perspective view 1

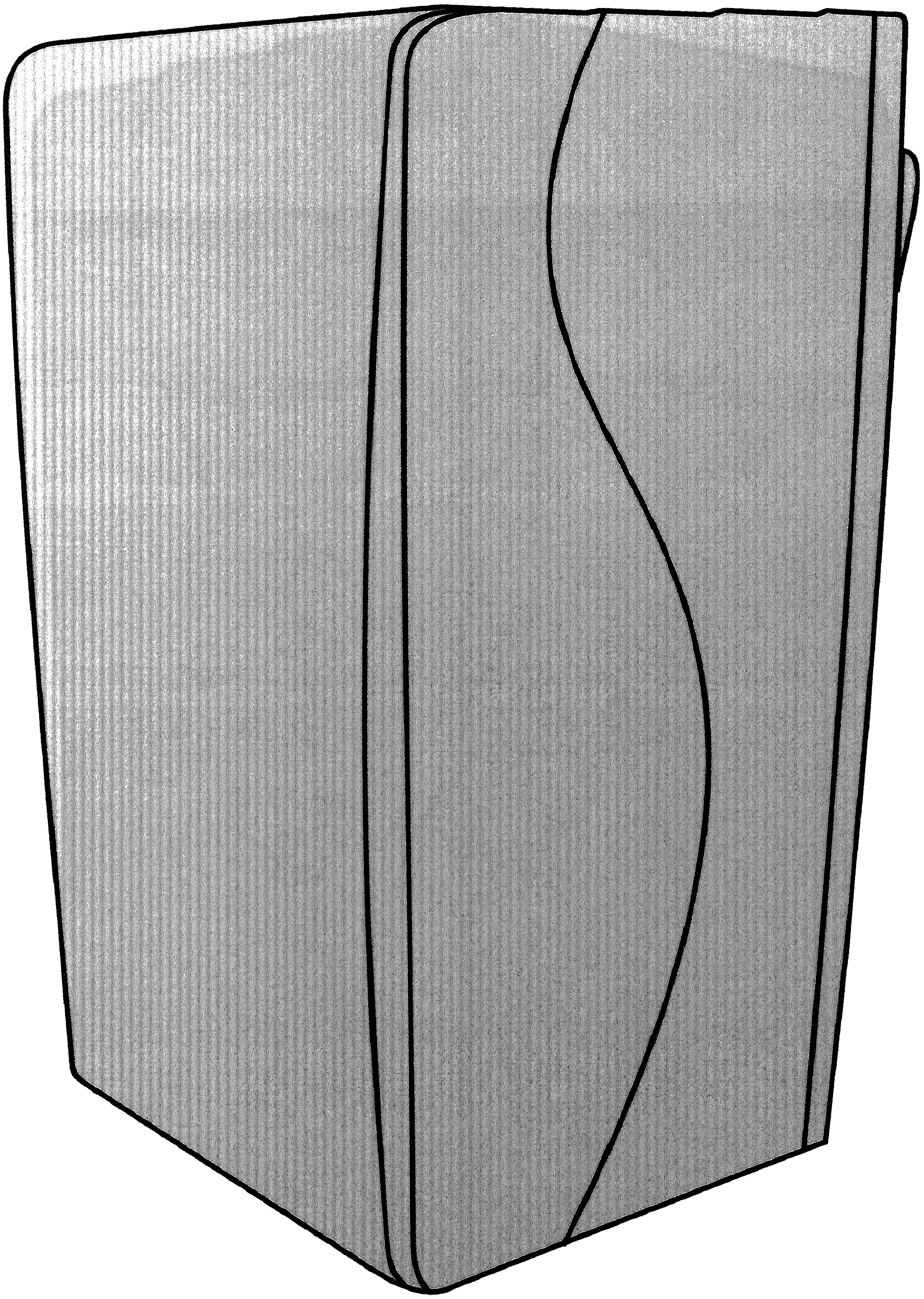


Fig 3.8: Perspective view 2

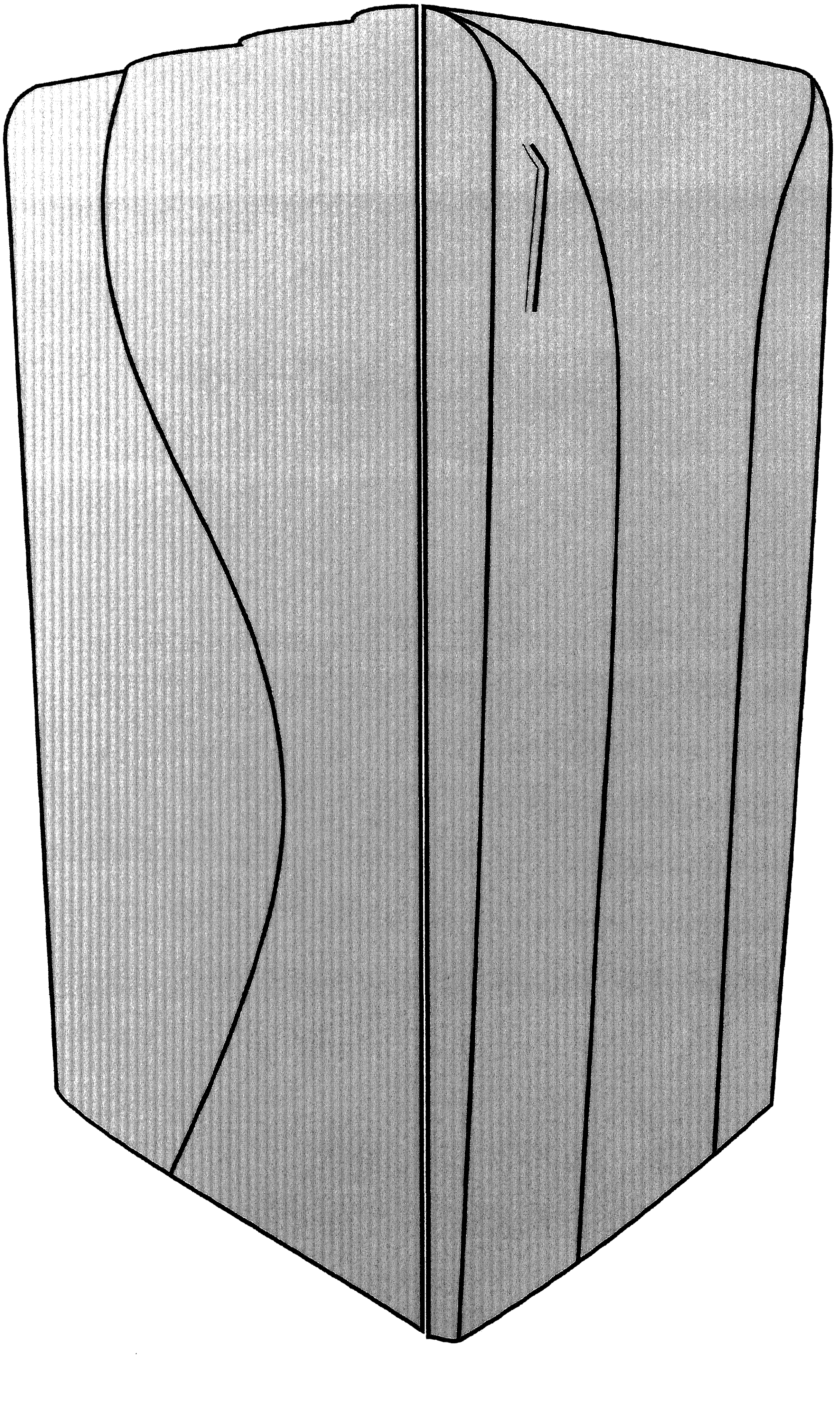


Fig 3.9: Perspective view 3

Chapter 4

PRODUCT FABRICATION

4.1 INTRODUCTION

Composite materials are made by combining two or more materials to give a unique combination of properties. Some widely used composites are GFRP, which consist of fibers and a polymeric matrix material; the reinforcing fibers or fabric material provides strength and stiffness to composite where as the matrix gives rigidity and environmental resistance. Reinforcing fibers are of various kinds like short fibers, long woven fibers etc, and they result in different properties. The fiber carries the load and strength is greatest along axis of fiber. The resin should wet each and every fiber of the fiberglass mat during fabrication for high quality products.

There are various mechanized ways of manufacturing composites. However, only wet lay up process and the associated raw materials will be discussed in this chapter. The development of the refrigerator is carried out with the wet lay up technique, and is insulated with polyurethane foam.

4.2 WET LAY UP PROCESS/ HAND LAY UP PROCESS

Wet lay up process is widely used for making prototypes of various products. This process is labor intensive. In this process, liquid resin is applied to the mold and then reinforcement layer is placed on top. A roller is used to impregnate the fiber with resin. Another resin and reinforcement layer is applied until a suitable thickness builds up. It is a very flexible process that allows the user to optimize the part by placing different types of fabric and mat materials. Because the reinforcement is placed manually, it is also called the hand lay up process. This process requires small capital investment and expertise and is therefore easy to use.

4.3 RAW MATERIALS

Usually Material selection for fabricating any product out of composites is driven by cost, ease of availability, ease of handling, processing and fabrication. The raw material requirement for part fabrication by wet lay up process is discussed below.

4.3.1 Fiber

The average fabricator has a choice of three types of reinforcing materials with which to construct a project. These are fiberglass, carbon fiber, and Kevlar®. All three have their attributes and shortcomings, and are available in numerous forms and styles.

Glass fiber is the most widely accepted and least expensive reinforcement is fiberglass. It has a modulus of about **70 GPa,** and strength of **2500 MPa**. It has been used successfully in many applications since the 1950's, and much is known about its

properties. It is relatively lightweight, has moderate tensile and compressive strength, is tolerant of both damage and cyclical loading, and is easy to handle and machine. Glass fiber predominates in the fabrication of commercial items.

The other two fibers carbon and Kevlar display excellent properties, but are expensive; hence, glass fiber was preferred over the other two for fabricating the refrigerator body.

Glass fiber is available in many forms and weaving styles. All three are generally available in tow (pure unidirectional fiber form), veil mats, and woven fabrics. Fiberglass is also offered in a pressed chopped strand mat option. This material is just what the name implies. The fibers are typically 25 – 50 mm in length and are randomly oriented. Chopped strand mat is not a very strong material because of the short fiber length. However, it is isotropic in its plane; that is, it is equally strong in all directions. This is the least expensive reinforcement form and is thus the most widely used. It is suitable for molds and part production.

4.3.2 Resin (Polymer)

Three types of matrix material are usually available, they being Polyester, epoxy, and Phenolic resins all three have their attributes and shortcomings, and are available in numerous forms and styles.

Polyesters are low cost resin systems and offer excellent corrosion resistance. The operating service temperatures for polyesters are lower than that for epoxies. They are widely used and easily available, it is the most common resin in building commercial

items and in building boats. Of the other two resin, Epoxy is the best but expensive and Phenolics are extensively in Russia but not popular elsewhere. Hence, polyester resin was used for fabricating the refrigerator.

4.3.3 Other Material Requirements

The glass fiber - resin system forms the basic raw materials for part fabrication by composite; however, other material requirements are:

- Gelcoat: A colored, polyester-resin material applied to the surface of a molded part. The gelcoat hardens to a smooth, durable form and becomes an integral part of the laminate. It provides cosmetic enhancement and weather-ability to a fiberglass laminate.
- Release agents (PVA, Waxpol, etc.): It prevents the polymer composite to stick to the mould or the die and helps in ejection of the piece.
- Metal sections: They reinforce the FRP Die / product.

4.4 MOLD AND TOOL MAKING

The three most critical in developing a new product are product design, processing engineering, and mold engineering. Obviously, these are not independent, and product designers need to think about the constraints of mold making and manufacturing process. There can be an impressive product design with wonderful aesthetics, but if the part cannot be manufactured economically, then it is not useful to consumers.

Mold and tool making are a challenging segment of the composites manufacturing area. A tool transforms the raw material to a given shape. Without the tool or mold, the

raw material cannot be shaped to the final dimension and size requirements of the part. The mold design for the wet lay up process is very simple as compared to other manufacturing processes, because the process requires mostly a room temperature cure environment with low pressures. Steel, wood, GRP and other materials are used as mold materials for prototyping process. Section 3.6.1 identifies the important criteria for mold design.

4.4.1 Mold Design Criteria

Shrinkage Allowance

In mold design shrinkage of the composite material is taken into account to make sure that the end product is of the desired shape and size after the part is cured. Shrinkage is the reduction in volume or linear dimensions caused by curing the resin as well as by thermal contraction of the material. For a composite material as well as mold material, the shrinkage allowance is determined and factored into the design of the part and the mold.

Coefficient of Thermal Expansion of Tool material and End Product

The coefficient of thermal expansion (CTE) is an important parameter for the mold design. Every material expands and contracts to a different extent when heated and cooled from a certain temperature. The CTE of the tool and the composite part should closely match to avoid residual stresses and dimensional inaccuracies in the end product. For a room-temperature cures system, the CTE consideration is not important

Stiffness of the Mold

During the fabrication of a part, the mold experiences significant pressure, especially in closed molding operations. The mold should not deform under such pressure, otherwise it may cause distortion in the part. The mold should be stiff enough to take processing pressures.

Surface Finish Quality

The surface finish of the end product relies on the surface finish quality of the tool. To obtain class '**A**' surface finish on the part, the tool surface should be of high quality. During part fabrication, the tool is waxed and dirt is removed to avoid the inclusion of any foreign material in the part.

Draft and Corner Radii

On vertical surfaces, a 1-degree draft angle is recommended. A generous draft angle promotes better material flow, reduced warpage and easier release from the mold. Sharp corners must be avoided during mold and part design. Minimum inside corner radii of 10 mm. and minimum outside corner radii of 5 mm. are recommended for better flow along the corner as well as for ease in part removal.

4.4.2 FRP Tooling for Open Molding Process

These are primarily used for open molding operations such as hand lay up, wet lay up and spray up processes. Open molds are made from a master pattern. Both the molds with which composite components are built and the master pattern from which the molds are created are critical to the quality of the end product. The master pattern could be an

existing product, such as boat hull, automotive fender etc. could be made by machining a a block of metal, wood, plastic, foam or any other material. The master model must be glossy and defect free to reduce the amount of sanding and buffing on the mould. Once the master model is ready, it is waxed with release agent for easy removal of the mould. The master is coated with release wax for three or four times in alternate directions and allowed to harden after each layer is applied.

The next step is to apply a tooling gel coat on the surface of the master. The tooling gel coat provides a hard glossy and long lasting surface on the mold. It is applied using a brush or spraying equipment. The gel coat is allowed to gel before applying any laminating material. To make sure the gel coat has properly gelled, the surface is lightly touched with a finger. If the finger does not stick or does not leave a slight a finger print mark on the gel surface, it is ready for lamination. After the gel coat is ready a laminate of short fiber composites are hand laid or sprayed. For large and stiffness critical structure, like the refrigerator cabinet and the door; the foam core material is embedded into the lamination to achieve a sandwich structure.

4.5 BASIC STEPS IN COMPOSITE MANUFACTURING PROCESS

There are four steps in composite part fabrication: wetting /impregnation, lay up, consolidation, and solidification. All composite manufacturing process involves the same four steps, although they are accomplished in different ways. A schematic of the wet lay up process is shown in Fig 3.8.1

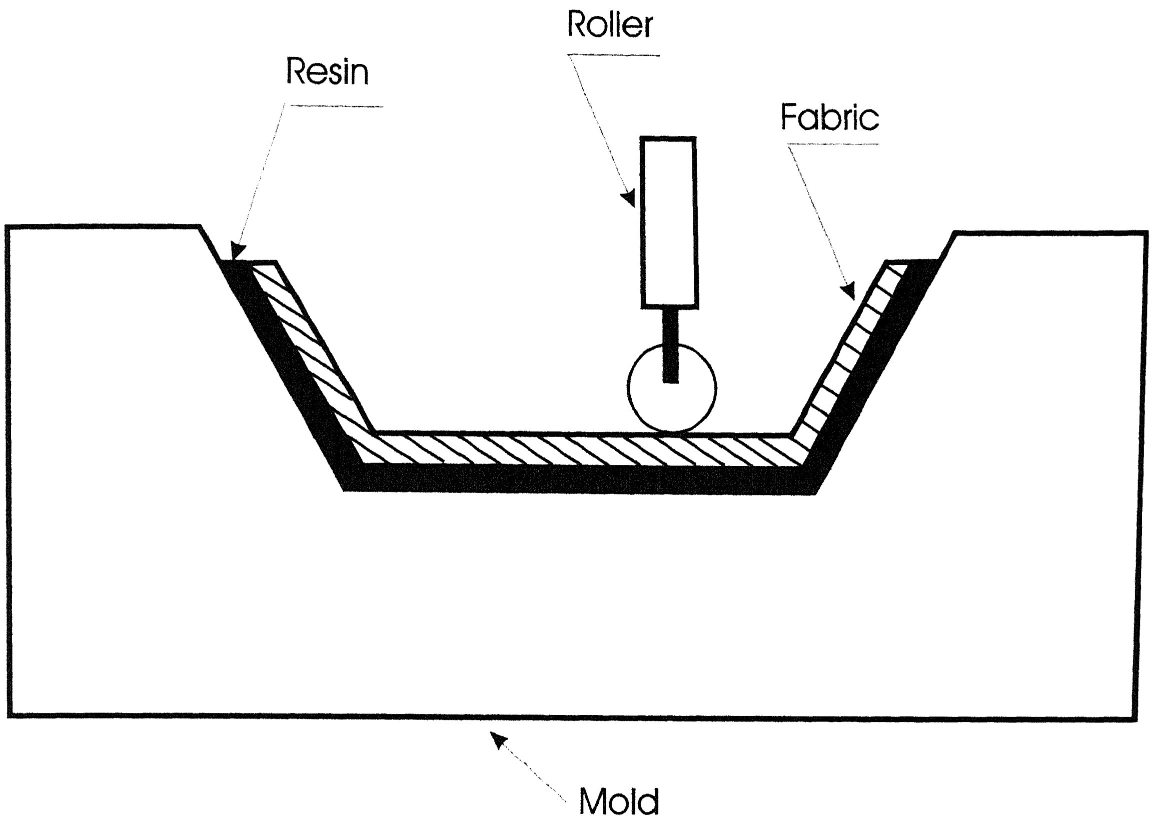


Fig 3.8.1: Schematic of the wet lay up process

4.5.1 Impregnation

Fibers and resins are mixed together to form a lamina, For example, in wet lay up process each fabric layer is wetted with resin using a squeezing roller for proper impregnation. The purpose of this step is to ensure that the resin flows entirely around all the fibers. Viscosity, surface tension and capillary action are the main parameters affecting the impregnation process.

4.5.2 Lay Up

Composite laminates are formed by placing fiber resin mixtures at desired angles and at places where they are needed. The desired composite thickness is built up by placing various layers of fibers and resin mixture.

The purpose of this step is to achieve the desired fiber architecture as dictated by the design. Performance of a composite structure relies heavily on fiber orientation and lay-up sequence.

4.5.3 Consolidation

Intimate contact is created between each layer of the lamina to ensure that all entrapped air is removed between layers during processing. Consolidation is very important in obtaining a good quality product. Poorly consolidated parts will have voids and dry spots

4.5.4 Curing

The final step is curing, which may take upto 24 hours for thermosets. The rate of curing depends on the resin formulation and cure kinetics. In thermoset composites the temperature is raised to obtain faster curing. Lower the curing time higher the production rate achievable by the process.

4.6 PART FABRICATION

Before going ahead with the fabrication of the refrigerator body, it was decided to fabricate a test panel. The test panel was made to experiment the composite manufacturing process and to learn the complexities involved in fabricating intricate shapes. Concept 8 (refer chapter 2) was chosen as the test panel to be manufactured out of composites. Fig. 4.1 shows the perspective views of the Test Panel and Fig 4.2 details the Test Panel.

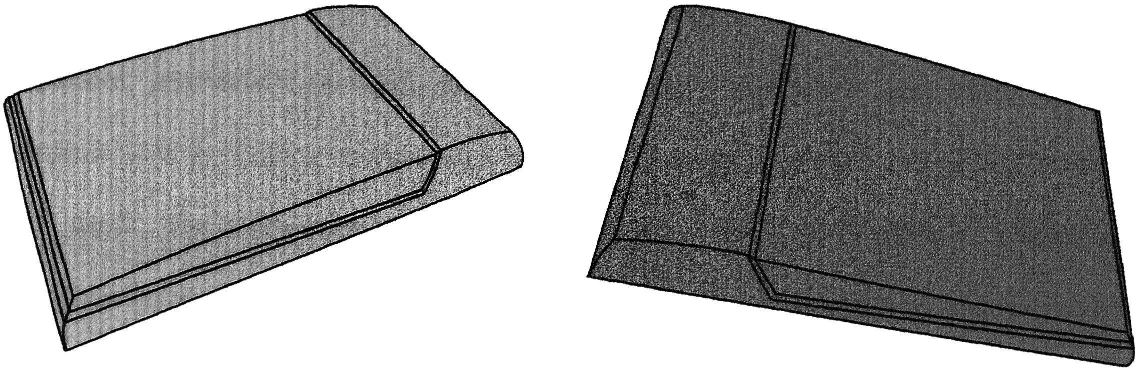


Fig 4.1: perspective views of the Test Panel.

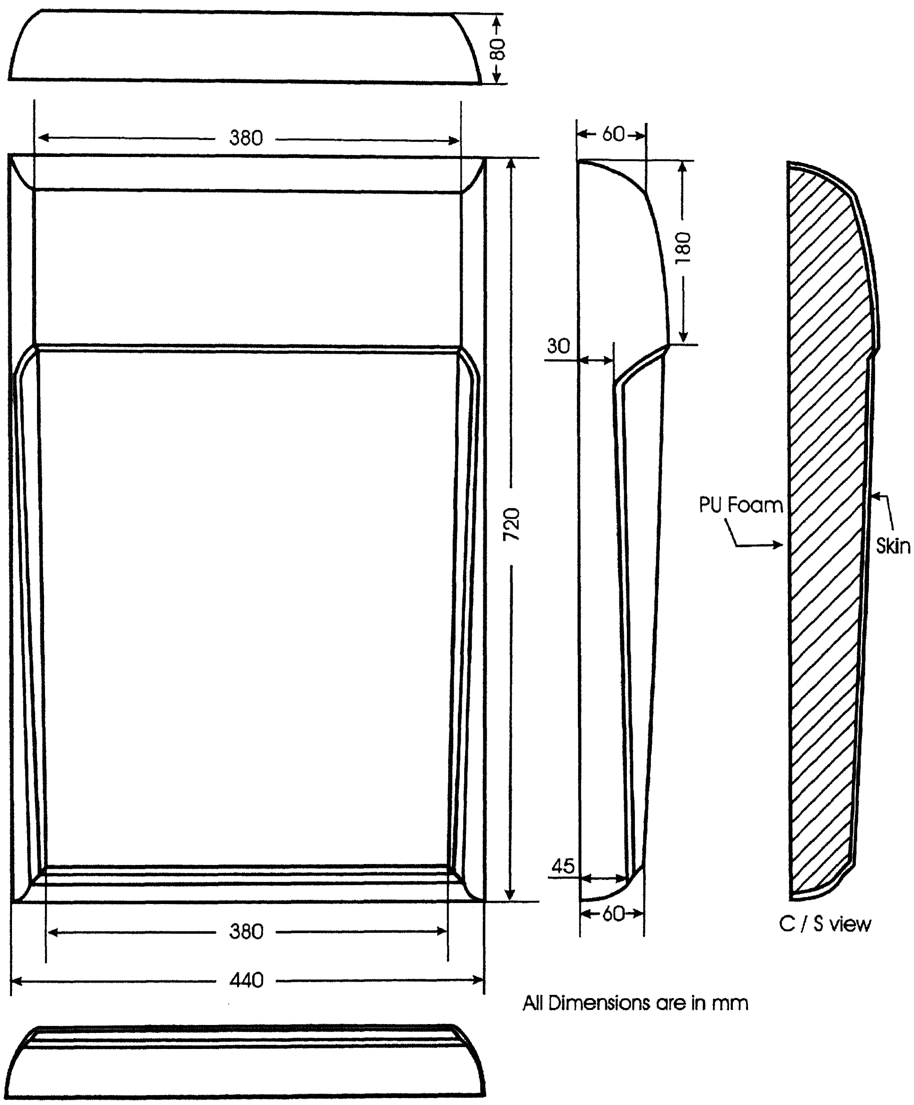


Fig 4.2: Details of the Test Panel.

The three major steps involved in fabrication of the test panel were the preparation of pattern, preparation of mold, preparation of panel. The pattern was made of MDF (Medium Density Fiber), cladded with sun mica laminate sheet. The mould was made of FRP itself. The composite test panel was built by applying a series of reinforcing fiberglass layers and polyester resin layers. A roller was used to squeeze out excess resin and create uniform distribution of the resin throughout the surface. By the squeezing action of the roller, homogenous fiber wetting is obtained. Since the test panel was made to resemble a refrigerator door, it was necessary to have an insulation layer. Therefore, pre-shaped foam panels of 35 Kg/m^3 were inserted into the skin as an insulation member. The part is then cured mostly at room temperatures and, once solidified, it is removed from the mold. Figure 4.3 shows the finished component

Foam panels also acts as a structural member. However it would have been desirable if foam was injected into the component with help of a foaming machine. But in the prototyping stage, foam panels worked as a reasonable alternative.

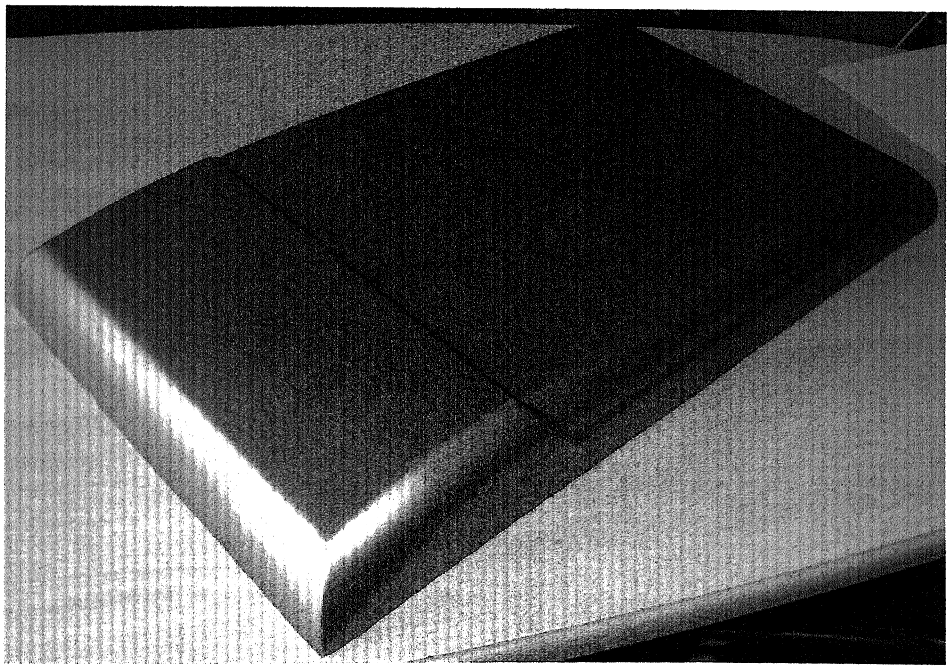


Fig 4.3: Finished component.

The overall process cycle time is dictated by the size of the component as well as the resin formulation used. For large – sized structures such as a body of a refrigerator, room temperature curing is commonly used. If the laminate to be made is thick then the wall thickness is built up in stages to allow the exotherm to take place without overheating. Quality control in the wet lay up process is relatively difficult. The quality of the final part is highly dependent on operator skill. The refrigerator manufacturing process out of composites is discussed in detail in the subsequent sections.

4.7 REFRIGERATOR MANUFACTURING PROCESS

The three major steps involved in fabrication of the refrigerator cabinet and the door are discussed in detail in this section. They are

- Preparation of Pattern
- Preparation of Mold
- Preparation of the Component

4.7.1 Fabrication of the Refrigerator Door

Preparation of Pattern for the Door

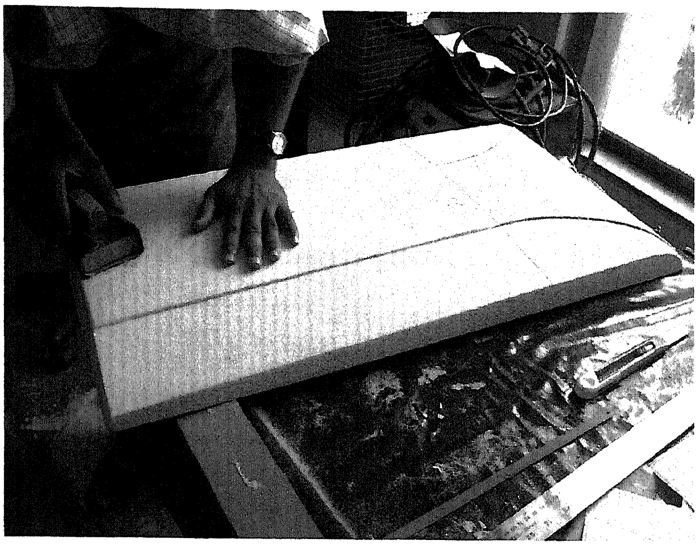


Fig 4.4: The replica of the required panel is prepared out of polyurethane foam of density 150 Kg/m³.

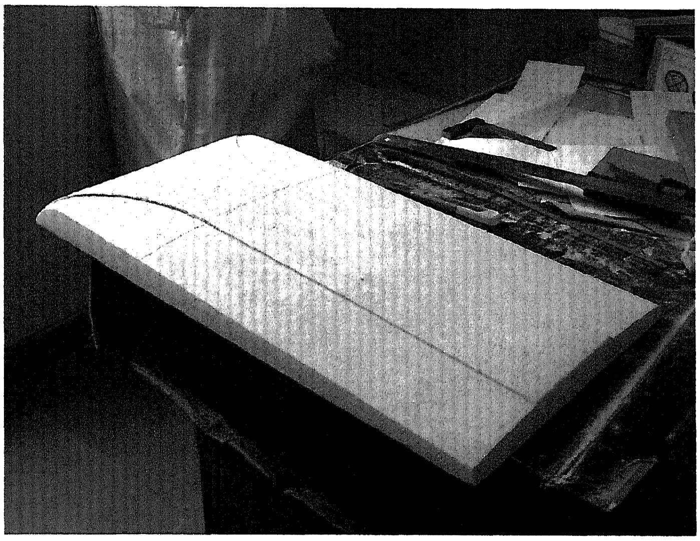


Fig 4.5: It is then coated with a paste of chalk powder and fevicol mixture, to fill the pores of the foam.

Fig 4.6: The panel is mounted onto a base plate. Surface is then sanded to get a good surface finish, and polished with wax, to get a shining surface. It also acts as a release agent.

Preparation of Mold for the Door

Once the surface of the pattern is prepared it is easy to cast the FRP die by the hand-lay up process. Following is the detail of the process:

- Two or three layers of PVA is applied onto the surface.
- Gel coat with the desired colored pigment is then applied.
- Once the gel coat has hardened, a layer of Glass fibers is placed on the surface and then impregnated with polyester resin.
- Using the brush the resin is uniformly distributed.
- Subsequent reinforcement layer are placed until a suitable thickness is built up.
- The part is then allowed to cure at room temperature.
- A flange of about 100 mm is also cast. The flange helps in the ejection of the component.

Fig 4.7: The die being cast on the pattern

Fig 4.8: Once the casting has cured, the die is ejected out of the pattern.

Fig 4.9: The die is then finished. All the sharp edges eliminated. And the working surface of the die is first sanded with a fine sand paper and then polished with wax to get a shiny surface.

Fabrication of the Door

Fig 4.10: The subsequent operations for fabricating the panel are similar to that of making the die. After applying 2-3 layers of PVA, Gel coat is applied and allowed to harden.

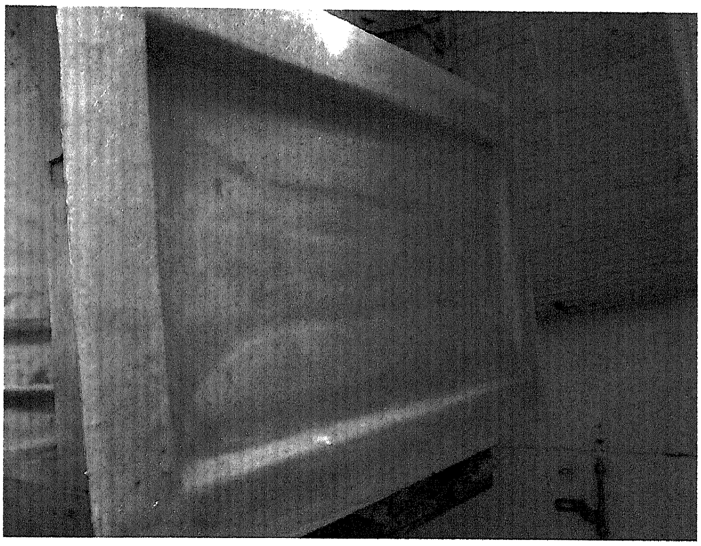


Fig 4.11: Once the gel coat has hardened, a layer of Glass fibers is placed on the surface and then impregnated with polyester resin

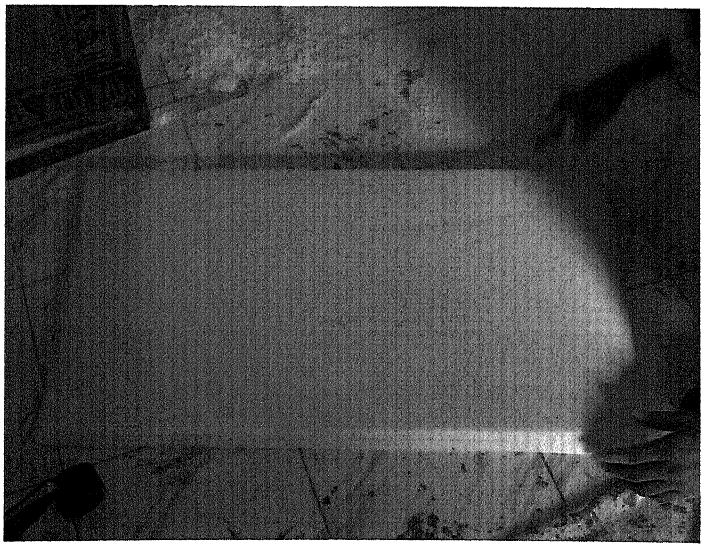


Fig 4.12: Once the fibers are laid, the insulation layer is prepared out of PUF of density 35 kg/m^3

Fig 4.13: The insulation layer is impregnated over the fibers and resin applied in the corners for bonding.

Fig 4.14: The cured component is then ejected and the flanges are trimmed. The surface is then cleaned of the PVA and the wax.

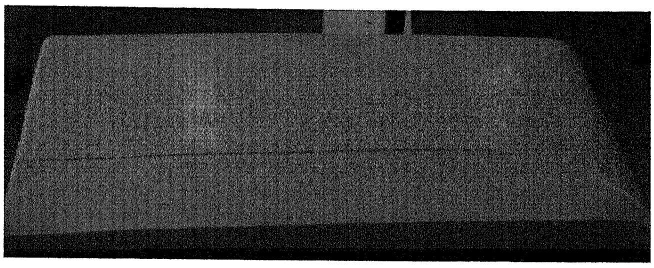


Fig 4.15: The finished door.

4.7.2 Fabrication of the Refrigerator Cabinet

The Fabrication of the refrigerator cabinet follows a similar procedure as that of the door. Difference being in the procedure adopted to fabricate the pattern. MDF (Medium Density Fiber) was used to make the pattern. To close the minute pores of MDF and to give it a good surface finish, the surface was primered with wood primer. The surface was then sanded with a sand paper. Subsequently the release agents were applied on to the surface followed by gelcoating and casting.

Fig 4.16: Pattern is prepared using MDF on the basis of the section drawing.

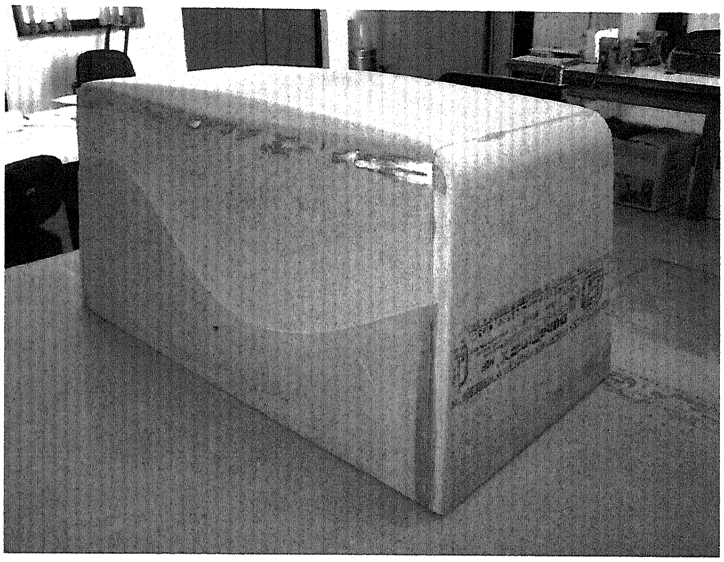


Fig 4.17: Full finishing of the pattern is done with fillers and Primer to get an excellent die.

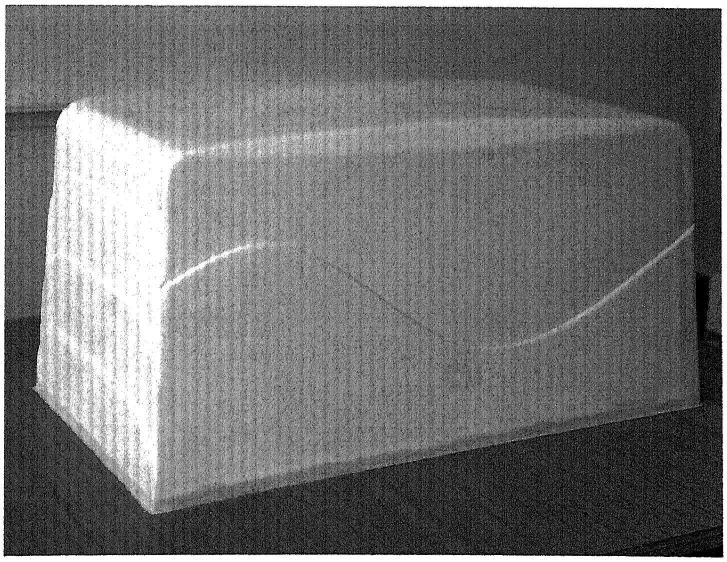


Fig 4.18: Gel coat applied on the pattern

Fig 4.19: Casting of the Split Die. Flanges are used on the periphery to make a press fit die and a nut – bolt arrangement

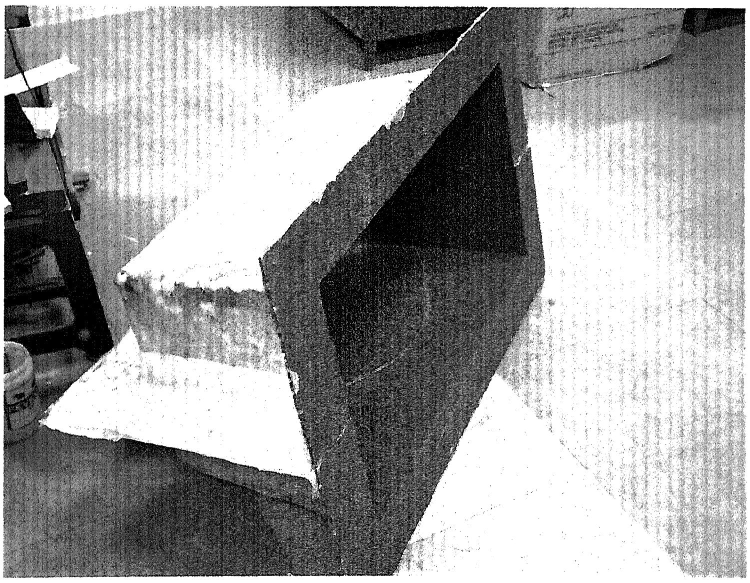


Fig 4.20: Split Die

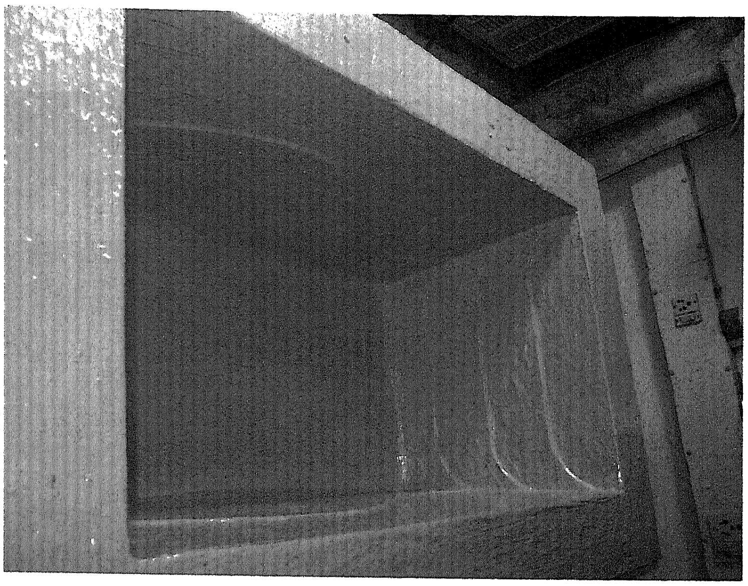


Fig 4.21: Die after applying gelcoat

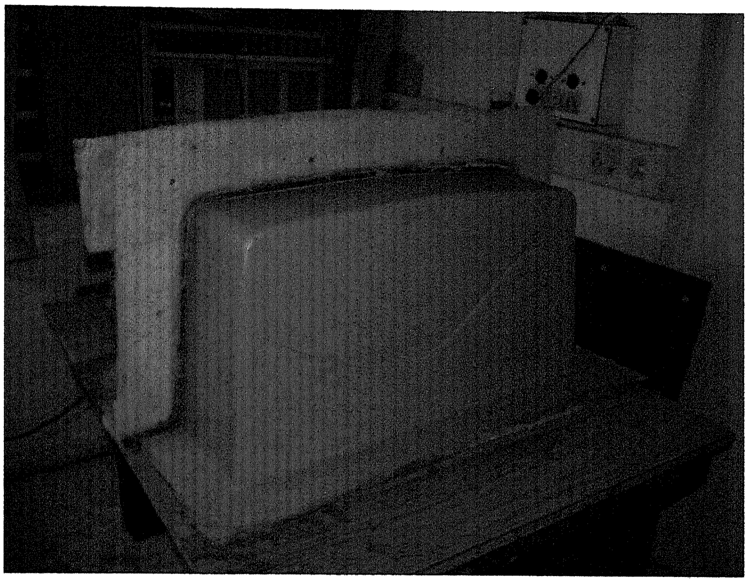


Fig 4.22: the component being ejected out of the split pattern

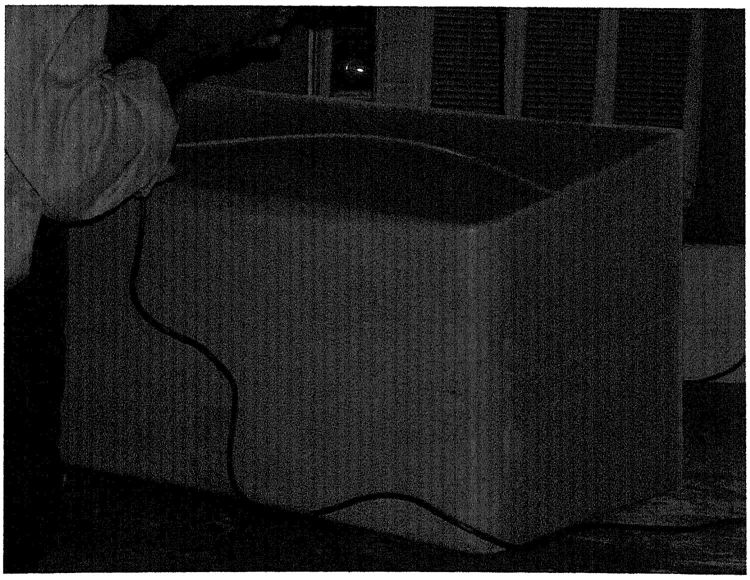


Fig 4.23: Cabinet skin being finished

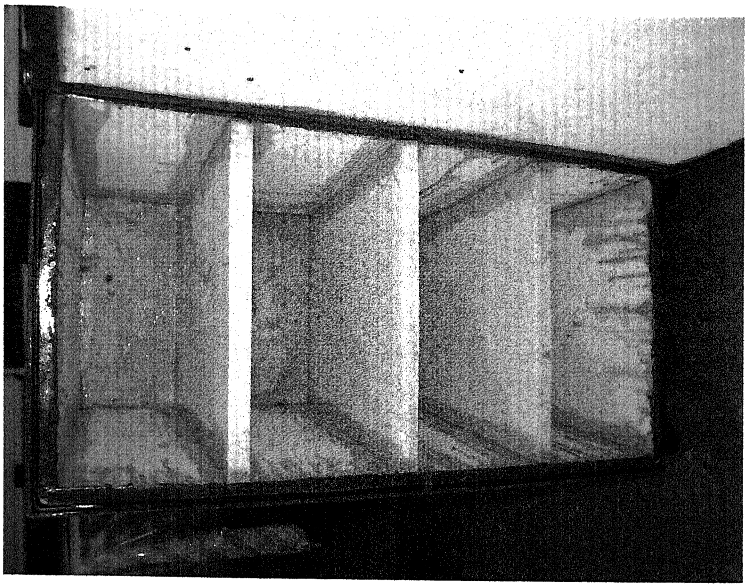


Fig 4.24: PUF of density 35 Kg/m^3 was then impregnated over the skin.
Since the skin was made of only one layer of GFRP, Foam was used as a structural member to provide rigidity to the structure.

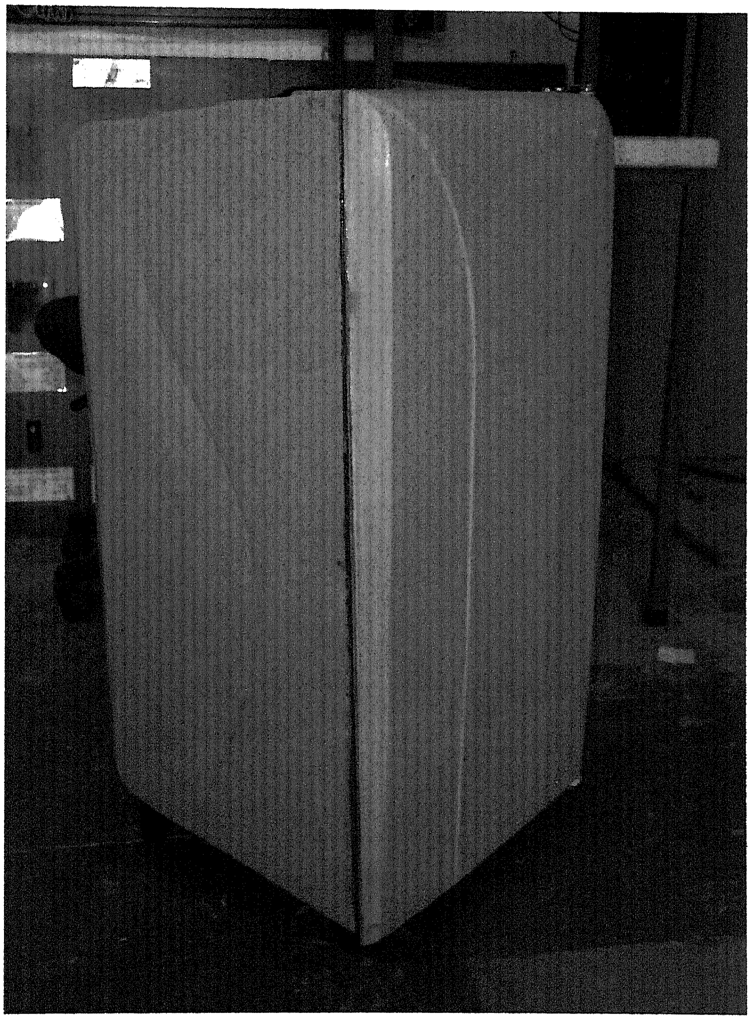


Fig 4.25: Assembled Refrigerator.

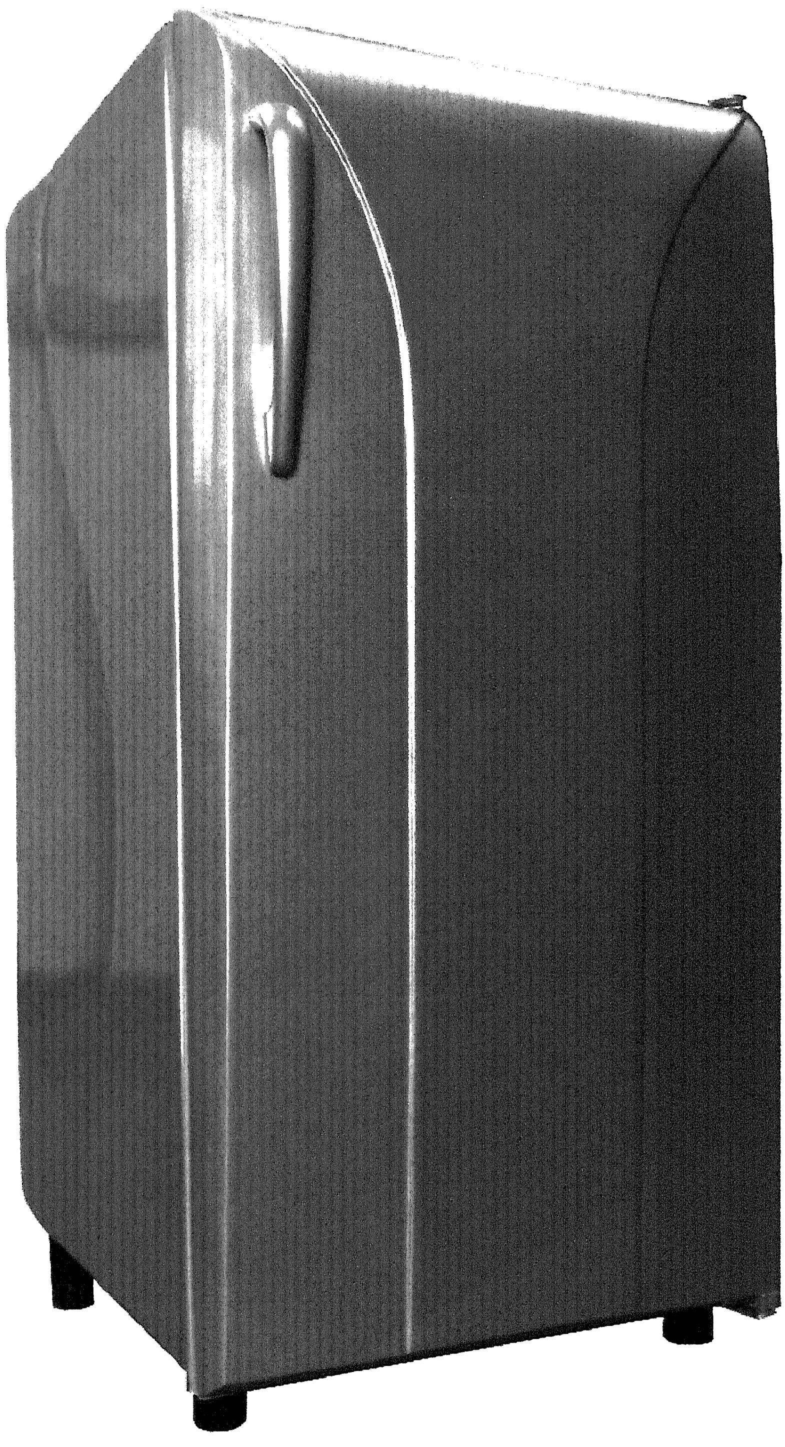


Fig: 4.26: Finished Refrigerator.

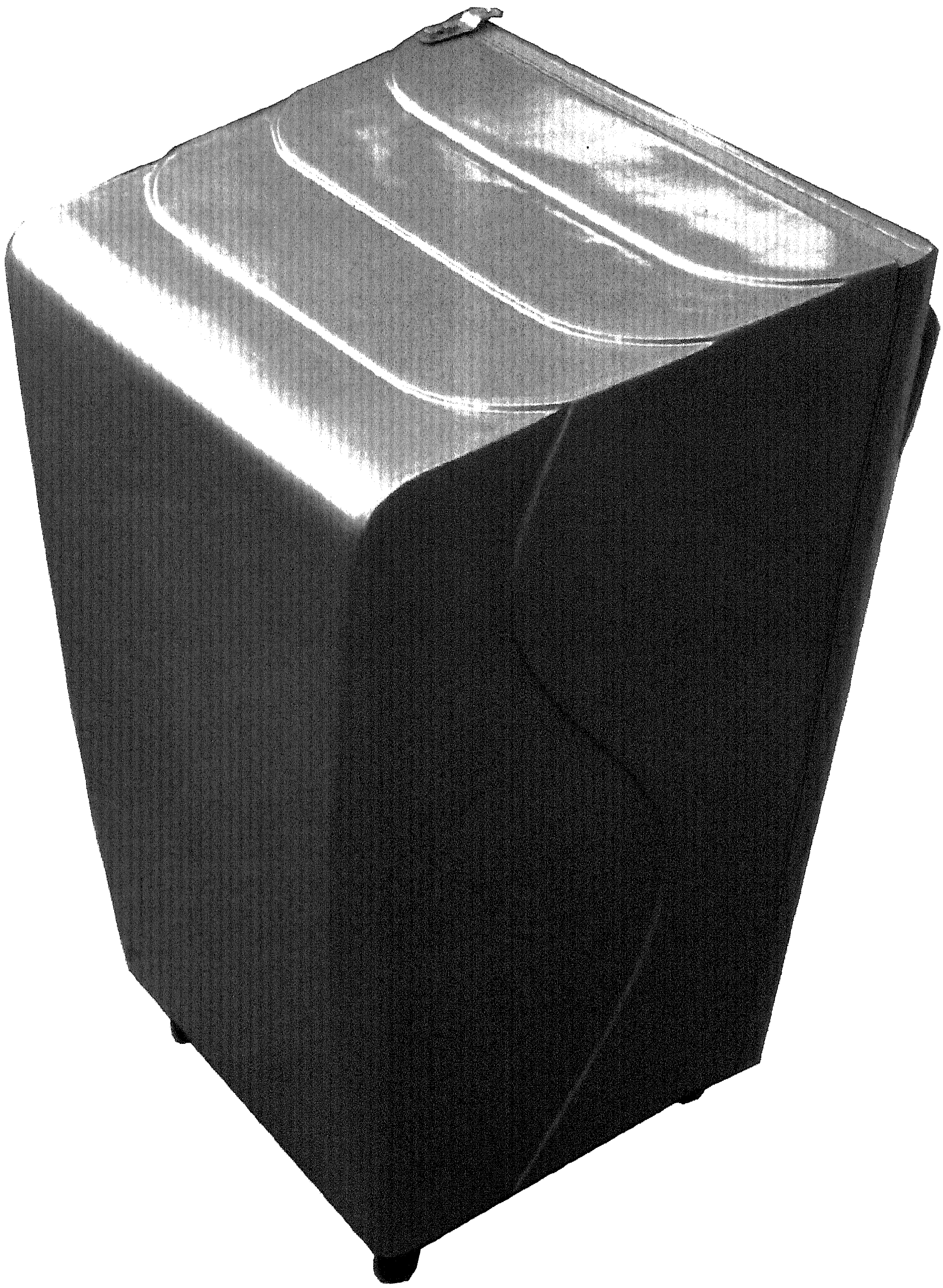


Fig: 4.27: Finished Refrigerator.

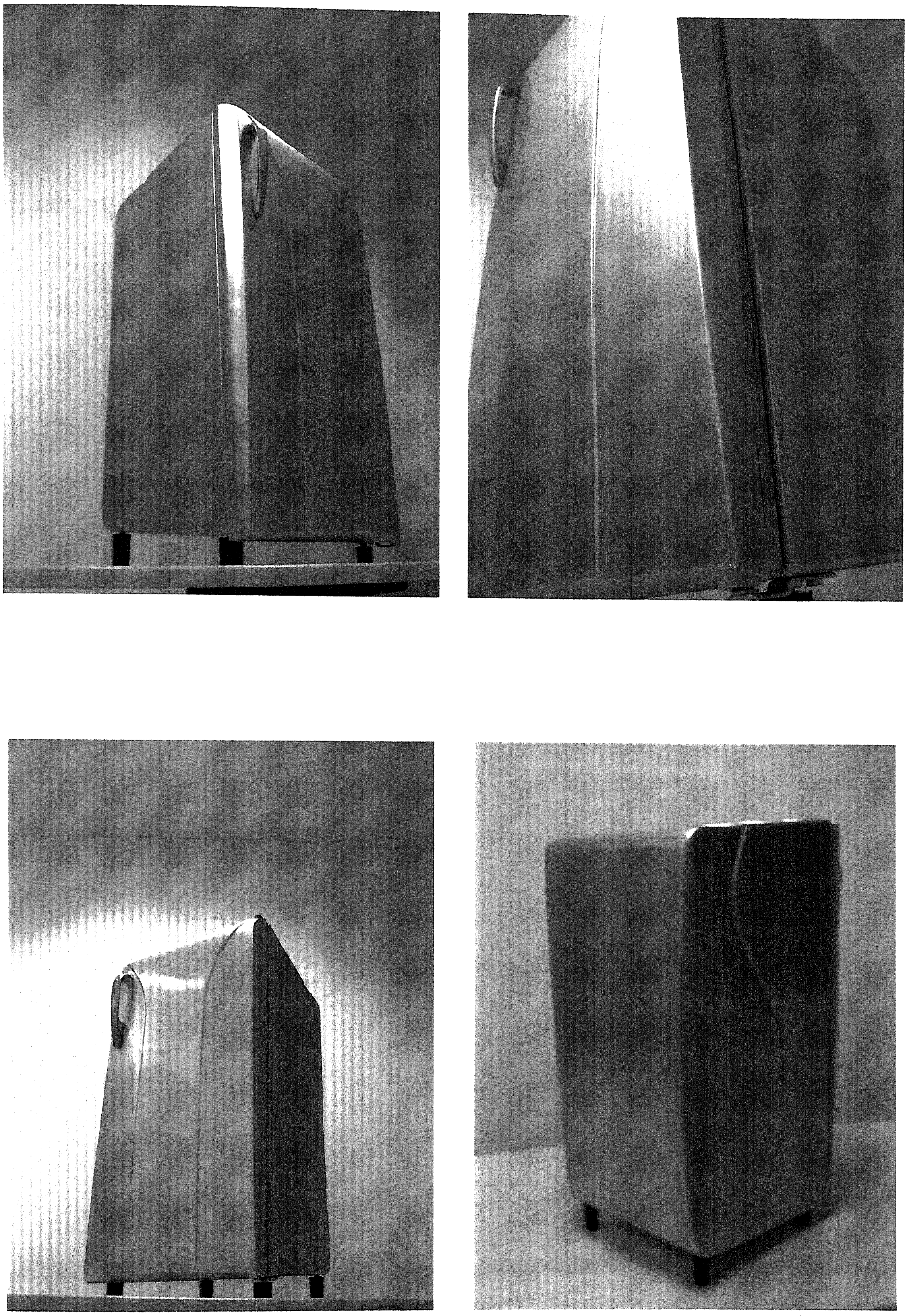


Fig: 4.28: Various views of the Refrigerator

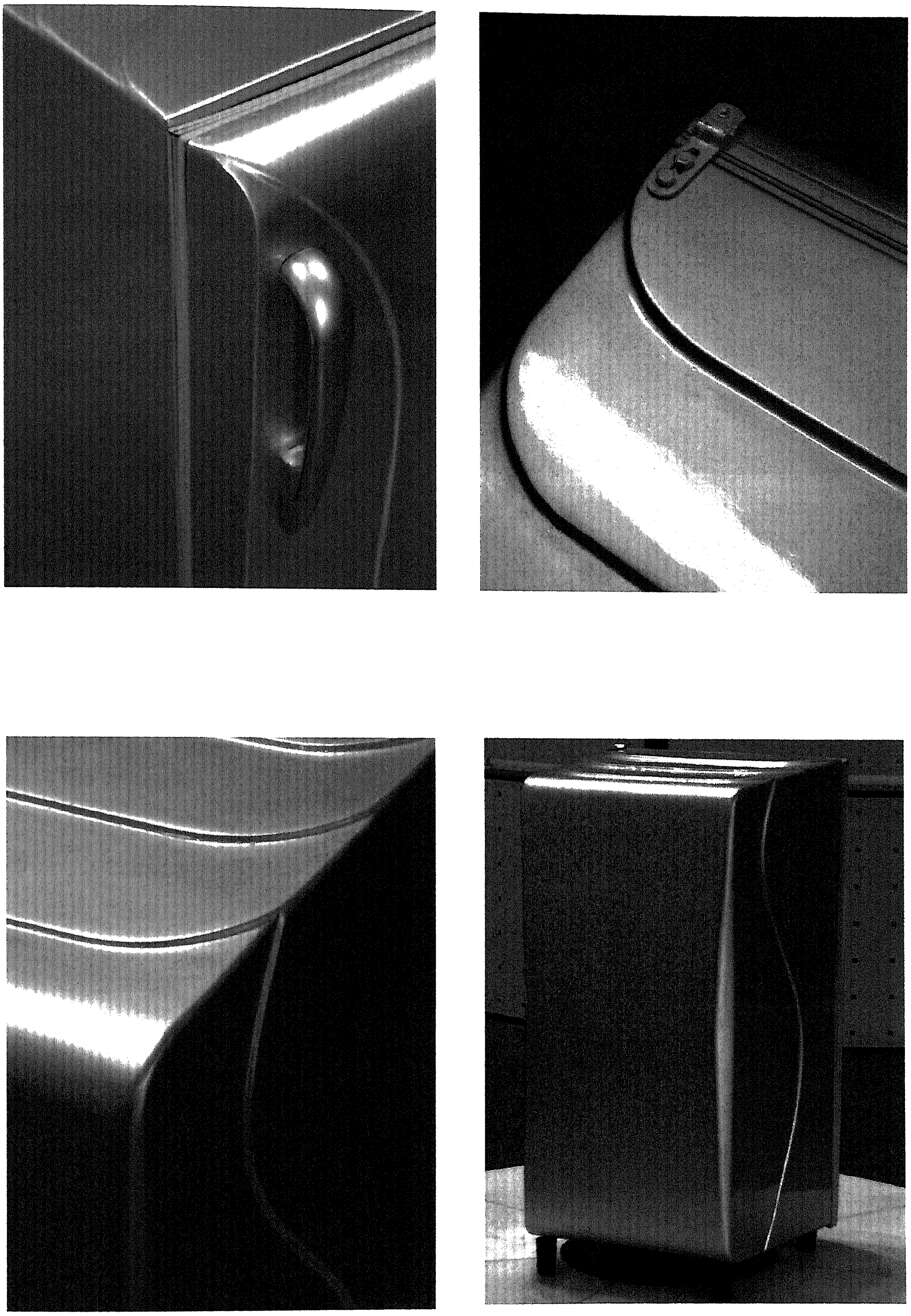


Fig 4.29: Various Details of the Refrigerator

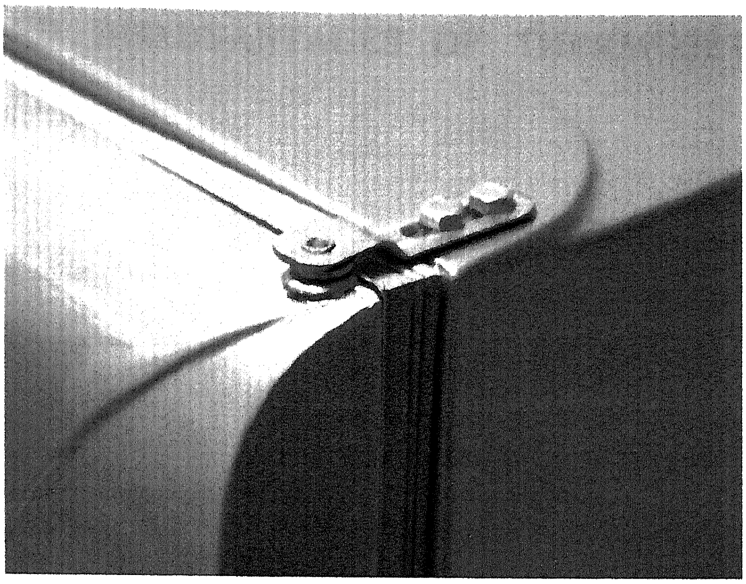


Fig 4.30: The door hinge.

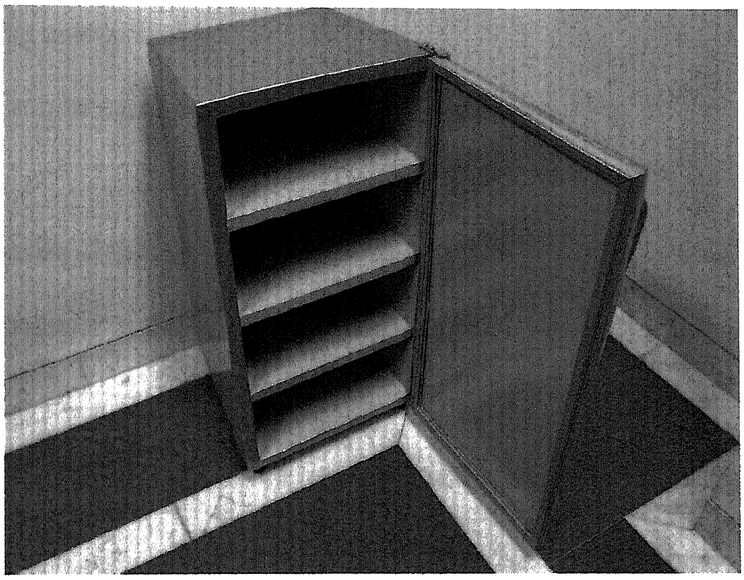


Fig 4.31: The inner details of the cabinet.

4.8 ADVANTAGES AND DISADVANTAGES OF THERMOSET COMPOSITE PROCESSING

Some advantages of the thermoset composite processing are,

1. Processing of thermoset composites is much easier because the initial resin system is in the liquid state.
2. Fibers are easy to wet with thermoset, thus voids and porosities are less.
3. Heat and pressure requirements are less in the processing of the thermoset composites thus providing energy savings
4. Simple low cost tooling can be used to process thermoset composites.

However they have the following disadvantages.

1. Thermoset composite requires a lengthy cure time and thus results in lower production rates
2. Once cured and formed thermoset composites parts cannot be reformed to obtain other shapes.

4.9 CONCLUSION

Wet lay up techniques was selected for fabricating the component and it was discussed in detail. A test panel was fabricated to understand all three stages of a component manufacturing; pattern making, mold preparation and component fabrication. Subsequently a cabinet and compatible door was fabricated. Thus the desired objective of making a lightweight refrigerator out of composites was achieved.

Chapter 5

CONCLUSION AND POSSIBLE FUTURE IMPROVEMENT

A refrigerator is one of the most important devices found in any house. The concept of refrigeration has existed since ancient times and it has undergone various configurational changes from an icebox to the present day mechanical refrigeration system. However the striking fact is that refrigerator has undergone very little cosmetic changes. It essentially still remains a box shaped structure. This is mainly due to the body being made of sheet metal panels. The tooling cost increases for sheet metals for complicated shapes, which directly affects the cost of the refrigerator. As such the refrigerator has become a basic necessity and cannot be highly priced.

However, with the advent of new materials like composites, these constraints can be addressed to. Infact in this thesis an attractive refrigerator body has been developed using polymer composites. Various concepts were generated. Out of which one concept was chosen and finally fabricated using the wet lay up process. Since fabricating components out of composites was a totally new domain, it was decided to take a simple

concept initially before going ahead with complex forms. The domain of this thesis was building an attractive nonfunctional prototype of the refrigerator from polymer composites.

Various processes involved where the pattern preparation, die making and the final component fabrication. Medium density fiber (MDF) and Polyurethane foam (PUF) (150 kg/m^3) coated with chalk powder were used as the materials for making the pattern. The die and the final component were made of polyester resin and glass fiber. Wet lay up technique was used for casting the die and the component. Polyurethane foam 35 kg/m^3 was used as the insulation layer and structural member for reinforcing the cabinet. The refrigerator cabinet and the door were finally assembled and given for painting. Thus the objective was achieved

However this was the first non functional prototype whose form tended towards being box shaped. Further improvements can be in terms of achieving organic shapes, and making working prototypes. Also since wet lay-up technique, which is labor intensive, was used to fabricate the refrigerator, methods can be devised for fabricating the refrigerator out of RTM machines and the vacuum bagging techniques.

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